STEAM STRIPPING AS AN EMERGENCY COUNTERMEASURE

by

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ABSTRACT

A preliminary assessment was made of the technical, logistical and economic feasibility of a mobile steam stripping unit for treating contaminated groundwater resulting from spills and containing volatile organic compounds. Most candidate priority pollutants reviewed from EETD's list are steam strippable. The unit at a design flow of
2000 L/h was investigated and was found to fit within the overall length of a box van, i.e. 4.88 m (16 ft).

The economic analysis concluded that a capital expenditure in the vicinity of $154,000 is required. Daily operating cost of such a unit would be approximately $850/day, transportation and set-up/dismantling time not included.

RESUME

Une étude préliminaire a été faite sur la praticabilité technique et économique ainsi que sur la logistique d'une unité mobile de strippage à la vapeur pour traiter les eaux souterraines contaminées par des produits organiques volatiles suite à un déversement accidentel.

La majorité des polluants prioritaires de la division des Techniques d'Intervention d'Urgence d'Environnement Canada peuvent être récupérés en utilisant cette méthode de traitement d'eau contaminée.

L'étude a porté sur une unité mobile de traitement ayant une capacité de 2000 L/h. Elle a déterminé qu'une telle unité pourrait être transportée dans un camion de type fourgonnette de 4.88 m de longueur. L'analyse économique a révélé que la construction de cette unité coûterait environ $154,000. et les frais d'opération seraient d'environ $850./jr, transport et assemblage/désassemblage non-inclus.

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SUMMARY

S.1 INTRODUCTION

The Environmental Emergencies Technology Division (EETD) of Environment Canada is in the process of evaluating various chemical processes as clean-up techniques for treating wastewaters containing volatile organic compounds (VOCs). CH2M HILL and Resources Conservation Co. have been engaged to provide engineering services for the conceptual design of a mobile steam stripping unit for such application. The overall objective of the study is to evaluate its technical, logistical and economic feasibility.

S.2 LITERATURE REVIEW

As the first step in evaluating the technical feasibility of steam stripping as a method of cleaning up spills or leaks of VOCs, a literature survey was conducted, both of published literature and unpublished work by CH2M HILL and RCC. A review of the physical properties and operating results for the 48 candidate priority pollutants identified by EETD showed that, with the exception of a few compounds, most candidate pollutants are steam strippable.

S.3 DESIGN BASIS

The operating flow for the unit is in the 400 to 2000 L/h range. The logistical feasibility of a unit with a design flow of 2000 L/h was investigated,

particularly with respect to the shipping constraints i.e. to fit in a box van with an overall length of 4.88 m (16 ft).

Feed concentration is likely to be less than 1000 mg/L. The system designed, however, has capability up to the solubility limit. More concentrated streams will be decanted prior to feeding to the stripping column. A 20% steam-to-feed ratio (w/w) and a 1.5% (w/w) overhead withdrawal-to-feed rate were used as a design basis.

The scope of the facilities excludes the feed, overhead and treated effluent tanks, boiler feedwater treatment system and other ancillary and support equipment. The concept of pre-assembled equipment units, quick-connect fittings, and pre-packed, modular column sections was adopted. Simplicity, flexibility and robustness of design were emphasized.

S.4 PROCESS DESCRIPTION

Three alternate process schemes, namely; the open steam, reboiling, and vapour compression evaporation systems were evaluated. The open steam system was selected for further analysis since it is attractive technically, logistically, and economically.

Steam generated in the boiler enters the bottom of the column and strips volatile components from the downflowing wastewater as it travels up the packing. The uncondensed vapour exits the column, is condensed in a air cooler and is subsequently subcooled with the feed stream. The insoluble liquids can be separated from the water in a decanter while the

aqueous phase is heated by the treated effluent and returned to the column as reflux. The feed is also preheated and enters the column with the reflux or slightly below the reflux point.

The equipment has been divided into four modules to facilitate shipment and set-up. Shipping by either box van with fork lift unloading or flat bed truck with crane unloading is feasible. The equipment has been arranged to fit within the most common door size, 2.13 m x 2.13 m and to fit within 4.88 m (16 ft) overall length. The estimated load is 4400 kg, which is within the legal limit for a 5-ton box van (7400 kg).

With prior procurement of ancillary equipment, field set-up time of the complete system is estimated to be about 16 hours (2-man crew plus 8-hour availability of boom truck operator). A fork lift and a boom truck or "cherry picker" are required for both loading/unloading and set-up/dismantle.

Utilities required for operation include:

Fuel: No. 2 Fuel Oil, 860 L/day

Electric Power: 220/208 V/60 Hz/Single phase, 5 kW, 90% power factor

Boiler Feedwater: 6.7 L/min fresh or treated water from the stripper softened to <1 mg/L total hardness

S.5 COST ESTIMATES

Both capital and operating cost estimates have been prepared for the open steam system. The capital cost comprises three components; equipment costs, assembly material and labour costs, and indirect costs. The indirect costs include construction overhead and profit and engineering. Not included in the cost estimate are boiler feedwater treatment system, fuel oil tank, overhead waste tank and treated effluent tank. Owner's costs in project management and control are also excluded.

The capital cost estimates for equipment, assembly and indirects are $73,000; $41,000; and $40,000 respectively, which result in a total sum of $154,000. Accuracy of these estimates is +30%/-15%.

The operating cost is divided into four categories; transportation, set-up, dismantle, and operation. The first three are incurred for each occurrence or operating site. The fourth is incurred per operating day.

On the basis of a distance of 500 km travelled, transportation cost each way is estimated at $400. Both set-up and dismantle costs are the same i.e. $1500 per occurrence. The operating cost is estimated at $850/day which includes labour, electric power, fuel and maintenance.

Within the range of 400-2000 L/hr of feed, both the capital and operating costs of the system vary only slightly.

S.6 CONCLUSION

It is concluded that construction of a mobile steam stripper is technically and logistically feasible.

Chapter 1
INTRODUCTION

1.1 AUTHORIZATION

CH2M HILL was retained by Environment Canada to evaluate the technical and economic feasibility of steam stripping for clean up of spills or leaks of volatile organic compounds and to prepare a conceptual design of a mobile pilot plant.

Resources Conservation Co. (RCC) served as a subconsultant to provide technical input relative to their proprietary steam stripper and overhead decanter system.

This report, together with an interim technical memorandum which examines the available literature regarding steam stripping of volatile organics, documents the results of the study.

1.2 BACKGROUND

The Environmental Emergencies Technology Division (EETD) desires to evaluate the use of steam stripping as a clean-up technique for spills and leaks of volatile organic compounds (VOCs). Typical emergencies for which such treatment would be appropriate would include spills resulting from transportation or in-plant accidents, and groundwater contamination from leaking storage tanks or landfill impoundments.

Materials suitable for removal by steam stripping include those with a low to medium boiling point and

a low to medium solubility in water. Examples are gasoline and diesel fuel, a variety of petrochemicals and solvents, wood preservatives, dry cleaning fluids, refrigerants of the freon type, and some insecticides.

The performance of steam and air strippers operating in the petroleum and chemical industries suggests that the technology may be suitable for the treatment of contaminated water. The advantage which steam stripping offers over air stripping is that steam is condensible, allowing for the removal of VOCs for recovery and disposal in a concentrated form, thus eliminating atmospheric emissions.

1.3 OBJECTIVES

The overall objective of this study is to determine the technical, logistical and economic feasibility of a mobile steam stripper for the removal of VOCs from water after spills or other emergencies.

To achieve this, the following specific objectives were established relative to project execution.

- To evaluate the effectiveness of removal of VOCs using steam stripping in other applications.
- To develop and evaluate alternative steam stripping schemes.
- To prepare a conceptual design and cost estimate for the selected alternative.

1.4 APPROACH

A stepwise approach to project execution was adopted, comprised of the following components:

Phase I

i) A literature survey was conducted to define past use and effectiveness of steam stripping for removal of VOCs from water.

ii) An interim technical memorandum was issued summarizing the findings from the literature review as well as unpublished work carried out by CH2M HILL and Resources Conservation Co.

iii) A design basis for the pilot plant was determined particularly with regard to:

- o scope of design
- o range of influent concentrations
- o preferences with respect to physical arrangement

Phase II

iv) Alternative steam stripping schemes were developed and compared to identify one most suitable for use in this application.

v) A process flow diagram with basic control strategy, flow and enthalpy balances, equipment sizing and equipment layout were prepared for the selected process.

vi) Treatment capability of the designed process was determined for selected pollutants using a computer process design program.

vii) Capital and operating costs were estimated for the proposed facility.

Phase III

viii) A project report was prepared.

Chapter 2
LITERATURE REVIEW

2.1 INTRODUCTION

An interim technical memo was issued at the end of Phase I documenting the pertinent published work available in the literature and relevant unpublished work by CH2M HILL and RCC on removal of VOCs from water by steam stripping. A preliminary review of the physical properties of the candidate pollutants and their impact on the design of a steam stripper as well as a comparison of two available computer process design programs were also included.

2.2 LITERATURE SURVEY

2.2.1 Sources

A computer search was conducted using five information data bases - Water Resource Abstracts, Compendex, Chemical Abstracts, NTIS and Engineering Index. The abstracts of the articles compiled under these data bases, with the exception of the Chemical Abstracts (CA) data base, were scanned. Since CA does not store the abstracts of the articles in its data base, it only permits a title search.

The key phrase used for the electronic scanning was steam strip (), which encompassed phrases such as steam strip, steam strips, steam stripped, steam stripping, steam stripper, and steam strippers, etc. Attempts to combine this phrase with other keywords

such as wastewater or organics proved to be undersirable since it resulted in very few articles being cited.

The search was performed on all 1966-April 1987 (inclusive) publications maintained on the Water Resources Abstracts data base, all 1970-April 1987 (inclusive) publications in the Compendex data base and all 1964-April 1987 (inclusive) publications in the NTIS database. Due to data overlap, the CA and the Engineering Index data bases were limited to the periods of 1982-April 1987 (inclusive), and 1980-April 1987 (inclusive) respectively. The Water Resources Abstracts and the Compendex data bases provided the highest number of pertinent references.

Of the documents cited, twenty were considered sufficiently relevant to warrant procurement. Together with in-house collection, the extracted reference materials amounted to fifty-eight articles. Some of the articles possessed in-house are unpublished documents, mainly in the form of confidential correspondence or inter-office technical memoranda.

The "Manual for Spills of Hazardous Materials" provided by EETD constituted the final document of the total of sixty documents reviewed.

2.2.2 Assessment of Literature Survey

Of the materials extracted, twenty-two articles dealt with the pulp and paper industry directly. Of these, eight documents were general in nature and included topics such as the comparison of steam and

air stripping, sources of various pollutants, reduction of steam stripper feed by pre-evaporation with vapour recompression evaporation (VCE), etc. There were eleven articles that reported operating results of full scale steam strippers installed in Kraft mills. Two pilot studies (air or steam stripping) were identified.

Twelve documents reviewed addressed priority pollutants directly. Two of these were theoretical studies concerning the treatability of the pollutants with steam stripping and/or the effluent concentrations attainable with the process. Three other papers recorded three separate pilot studies of priority pollutants stripping using air as the stripping medium (combination of air and steam in one). The remaining of the documents were not as specific and steam stripping was mentioned merely as one of the processes in treating hazardous wastes in many of these articles.

Of the articles reviewed, seven were devoted to mathematical modelling/simulation of the steam stripping process or process design of steam strippers. Another six focused on the presentation of physical properties such as boiling points, vapour pressures, Henry's Law Constants, activity coefficients, etc.

Steam stripping was also extended to the treatment of radioactive wastes, refinery and oil shale wastewaters, geothermal fluids and wastes from the coal conversion process and fertilizer industry. These were covered separately in eight articles.

Five papers reviewed were considered not applicable to this study.

2.3 PROCESS DESCRIPTION

Stripping operations involve passing a gas or vapour through a liquid with sufficient contact that the volatile components are transferred from the liquid to the gas phase. The driving force for such an operation is the concentration differential between the liquid and vapour phases.

Steam is often used as the stripping medium in industrial applications where improved removal is obtained at elevated temperatures. The operation is usually carried out in a stripping tower with the vapour phase introduced at the base of the tower while the liquid feed is introduced at or near the top. Steam may be introduced as live steam or as reboiled steam through a heat exchanger or reboiler. The steam leaving the top of the tower contains the volatile contaminants. It is normally condensed and a portion of the condensate is returned to the tower as reflux. The overhead accumulator would operate as a decanter for insoluble liquids. The tower may be fitted with trays or filled with packing for enhancing contact between the two phases.

The section of tower below the feed point is called the stripping section and is used to increase the purity of the bottoms product. The section above the feed point is called the rectification section and is used to purify the overhead product. A simplified process schamatic is shown in Figure 2-1.

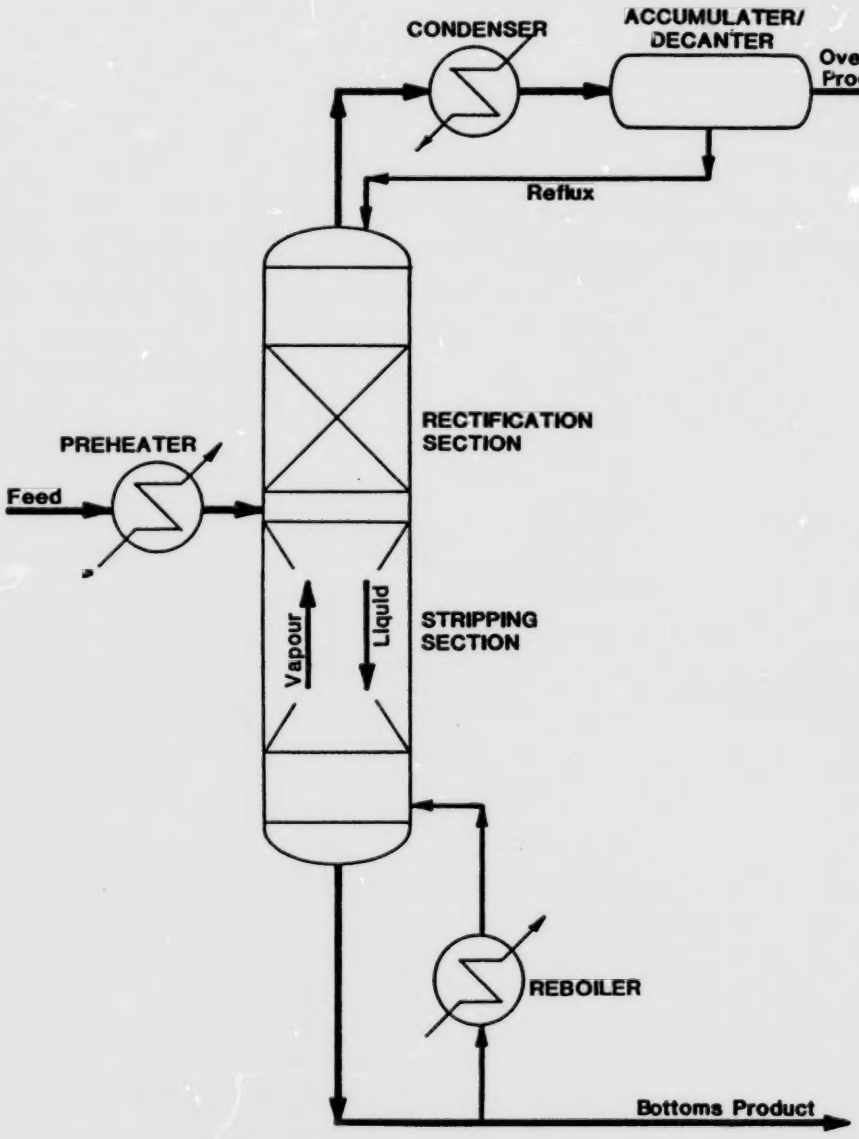


Figure 2-1
SIMPLIFIED PROCESS SCHEMATIC

The technical success of steam stripping or steam distillation hinges on differences in the thermodynamic properties of the two components. The vapour phase created by heating a liquid mixture must have a different composition than the original liquid phase. Several methods are used to quantify the differences in composition. The vapour-liquid equilibrium "constant" which is rarely constant but varies with composition is most useful for design at high concentrations. In dilute solutions it is more nearly constant and is called the Henry's law constant. Pure component vapour pressure and conversely, boiling point are indicators of a compound's behavior in a mixture, however non idealities in mixture behavior such as hydrogen bonding and ionization lead to much different performance than pure component properties would indicate. The liquid-liquid activity coefficient is used to account for these differences.

2.4 RESULTS FROM LITERATURE

2.4.1 Removal of Inorganic Gases

Steam stripping is widely used in the petroleum industry for the removal of carbon dioxide, hydrogen sulphide and ammonia from refinery wastewaters (References 19, 21, 56, 58). The stripping tower is commonly known as a sour water stripper. Steam stripping is also the principal process used in ammonia stripping of wastewaters from various sources including the synfuel (References 23, 58) and fertilizer (Reference 45) industries, and also radioactive wastes (Reference 20).

Successful attempts at steam stripping of geothermal condensates to remove hydrogen sulphide have been reported (Reference 60). Free cyanide and hydrogen sulphide have been stripped along with ammonia from oilshale wastewaters (Reference 19).

The effective stripping of gases such as carbon dioxide, hydrogen sulphide and ammonia by steam is attributed to the concomitant reduction of the pKa of the ion-gas equilibrium and the solubility of the gas at elevated temperatures (Reference 56), i.e. the ionic form is being converted to the gaseous form which is more easily stripped. The stripping of these gases by steam involves the following steps:

i) the conversion of ionic species of the dissolved gases, such as ammonium, bicarbonate and carbonate into their neutral gaseous forms, i.e. NH_3 and CO_2,

ii) the presence of a concentration driving force from the liquid to the steam phase

iii) the diffusion of the gases from the bulk solution to the liquid-steam interface, and

iv) the transfer of the gas through the liquid-steam interface into the steam phase

2.4.2 Removal of Organic Compounds

The most common application of stripping for removal of organic components is found in the pulp and paper industry. This is evidenced by the numerous installed facilities for steam stripping of BOD,

toxicity, total reduced sulphur (TRS) and other organic materials from the foul condensates.

The extent of removal of a compound by air stripping is governed primarily by two factors (Reference 3). One is the tendency of the compound to establish an equilibrium between the gas and liquid phases, i.e. Henry's Law Constant, and the other is the contact opportunity (the intensity and duration) of aeration. Volatile organic compounds with Henry's Law Constants of 10^{-2} to 10^{-3} atm. m^3/mol are considered good candidates for air stripping. Extractable and volatile organics with Henry's Law Constants less then 10^{-3} to 10^{-4} atm. m^3/mol may require high temperature air stripping or steam stripping for effective removal (Reference 4).

The principal index used to estimate steam-stripping capability is the boiling point of the organic compound. A compound predicted to have good steam-stripping characteristic would exhibit a relatively low boiling point (<150°C), plus an acceptable Henry's Law Constant value (References 1, 3). For compounds less volatile than water, the ability to form minimum boiling azeotropes or heteroazeotropes is considered indicative of good potential. In these mixtures, heating a dilute solution will result in a vapour phase richer in the contaminant even though the contaminant has a lower vapour pressure than water. The azeotrope will prevent production of a pure overhead stream, but since the object is only to purify the underflow then this is not a problem.

Air stripping has been successful in reducing volatile organics to very low levels at a number of locations. While there are significant differences between air stripping and steam stripping the mass transfer principals remain the same. The main differences between the two are:

- Air strippers designed to remove trace organics typically use much higher gas rates than steam strippers.

- Temperature and therefore vapour pressures in air stripping are much lower than in steam stripping.

- Azeotropes are not a concern in air stripping.

- Concentration and recovery of contaminants is not normally practiced with an air stripper. On the other hand, a steam stripper can be designed to not only remove the contaminants, but also to concentrate the contaminants. In the pulp and paper industry, these contaminants can be concentrated sufficiently to yield a product that will support its own combustion (Reference 13).

With due consideration of these differences, the results of air stripping operations can be related to steam stripper operations.

2.4.2.1 Pulp and Paper Industry

The main sources of contaminated condensates at a Kraft pulp mill include the flash steam condenser,

the multiple-effect evaporator train and in those mills recovering turpentine, the decanter underflow (References 11, 12, 13, 24, 39). The contaminants in the condensate include methyl mercaptan (CH_3SH), dimethyl sulphide ($[CH_3]_2S$), dimethyl disulphide ($[CH_3]_2S_2$), hydrogen sulphide (H_2S), terpenes (such as ∂-pinene and limonene), methanol (CH_3OH), ethanol (CH_3CH_2OH) and acetone ($[CH_3]_2CO$) (References 11, 24). Of the water-soluble components, methanol, ethanol and acetone are the major steam-volatile organic compounds. The solubility of turpentine, normally water insoluble, rises when other solvents such as methanol are present (Reference 24). While the principal odour-contributing substances are terpene and sulphur compounds, the principal BOD substances in the condensates are methanol and also some terpene compounds (References 13, 24).

Literature data indicate that air stripping is effective in removing 90% or more of the TRS compounds and make a significant reduction in the toxicity, but can reduce BOD by only 10-20% (References 13, 27).

Steam stripping reduces TRS and toxicity by more than 95% and BOD by 60-85+% (References 85, 32, 33, 34, 38, 44). The literature indicates that BOD removal improves with increasing steam ratio; e.g., 30% removal at 5% steam ratio, and 90% removal at 20% (Reference 10). Usually, the process is designed for a steam rate 15-18% by weight of the feed rate with an expected BOD removal of 85% (Reference 13).

A study by Guttierrez et. al. (Reference 10) quantified steam stripping efficiency for phenol. Stripper steam/ feed ratios varying from 5.6 to 14.4% by weight were noted in a survey of five installations and phenol removals from 0.4 to 61% were reported. This variation was attributed to the rectification section rather than to the steam ratio, however. The two highest removals recorded, 49% and 61%, were achieved by mills operating with a rectification section at steam ratio of 6.4% and 13.3% respectively, whereas 0.4% removal was reported for the mill operating at 14.4% steam ratio.

Removal attained for methyl mercaptan at 10% steam ratio was reported to be 85-90% (Reference 29). At 15% steam, the methanol removal achieved was 98% (Reference 30) with the corresponding overhead methanol concentration being 15-20%. The turpentine collection also increased by 20% (Reference 30). As steam ratio increased to 20%, the removal of dimethyl disulphide and overall sulphur was 95% and 98% respectively (Reference 27).

Operating results and conditions of the full scale air or steam strippers and pilot studies in the pulp and paper industry as identified in this literature review are presented on the data sheets attached in Section 2.9. Since results quoted in the literature were predominantly in terms of BOD, toxicity or TRS removal and seldom in terms of specific compounds (with the exception of methanol), the usefulness of these data for design purposes in removing volatile organic pollutants from wastewaters is limited.

2.4.2.2 Organic Priority Pollutants

Recorded results of steam stripping of organics outside of the pulp and paper industry are sparse. Studies were principally carried out on industrial wastewaters such as oilshale wastewaters, hazardous wastes and synfuel effluents. Contaminated groundwater has also been used.

Three pilot studies were identified in the literature review. Two of the studies were concerned with air stripping and the remaining study used a combination of air and steam as the stripping medium. The operating results and conditions of these studies along with in-house and RCC data are described on the data sheets.

Trichloroethylene and tetrachloroethylene have been shown to have been air stripped to less than 0.001 mg/L from a feed condition of 150 mg/L (in-house data), thus achieving removal efficiency of greater than 99%. Similarly, air stripping of trichloroethane, dichloroethene and acetone has resulted in removals greater than 90% (in-house data).

The 48 candidate priority pollutants for steam stripping as identified by EETD are classified under their respective family classes in Table 2-1. Reported percentage removals, for each of these candidate compounds, where available, are also presented. These data are consolidated from operating results presented on the data sheets and from theoretical sources.

TABLE 2 - 1

REPORTED REMOVAL OF CANDIDATE COMPOUNDS

CHEMICAL FAMILY	CANDIDATE COMPOUND	STRIPPABILITY (Note a)	REMOVAL EFFICIENCY (%)			
			STEAM		STEAM & AIR	AIR
			THEORETICAL (Note b)	ACTUAL	ACTUAL	ACTUAL
Aldehydes	Formaldehyde	6				
	Butyraldehyde					
Ketones	Acetone			>99.81 (P&P, Ref.39)		85.40 (Ref. 54)
				>98.00 (RCC)		>99.00 (In-house Data)
	Methyl Ethyl Ketone			>99.58 (P&P, Ref.39)		88.90-99.70 (Ref.48)
	Methyl Isobutyl Ketone				~100 (Ref.4)	
Alcohols	Methanol			62.00-98.00 (P&P)		90.00 (P&P, Ref.35)
				99.00 (RCC)		85.40 (Ref.54)
	Ethanol			>99.94 (P&P, Ref.39)		84.60 (Ref.54)
	Isopropanol					
	Butanol					
	2-Ethyl Hexanol					
	Ethylene Glycol					
	Propylene Glycol					
Alkanes	n-Hexane					
Carboxylic Acids	Formic Acid	6				
	Acetic Acid	6				
Amines	Methylamine					
	Ethanolamine					
	Morpholine					
Dienes	1,3 Butadiene					
Unsaturated Carbonyl Compounds	Acrylonitrile	1	(50,16,0.085,100)			
	Methyl Methacrylate					
Alicyclic Hydrocarbons	Cyclohexane	1				
Aromatic Hydrocarbons	Benzene	1	(50,7,0.005,100)	95.00-99.00 (Ref.52)	~100 (Ref.4)	
	Toluene	1	(50,7,0.003,100)	73.00-92.00 (Ref.52)	~100 (Ref.4)	
	Styrene	1		98.00-99.00 (Ref.52)		
	Ethyl Benzene	1	(50,6,0.004,97)	86.00-93.00 (Ref.52)	~100 (Ref.4)	80.00 (Ref.52)
	Isopropyl Benzene					
Alkyl Halides	Vinyl Chloride	1	(50,6,0.002,100)			
	Methylene Chloride	1	(50,8,0.006,100)			99.6
	Ethylene Dichloride	1		99.00 (Ref.52)		
				>98.00 (RCC)		

TABLE 2 - 1 (Cont'd)

REPORTED REMOVAL OF CANDIDATE COMPOUNDS

CHEMICAL FAMILY	CANDIDATE COMPOUND	STRIPPABILITY (Note a)	REMOVAL EFFICIENCY (%)			
			STEAM		STEAM & AIR	AIR
			THEORETICAL (Note b)	ACTUAL	ACTUAL	ACTUAL
	Chloroform	1	[50,8,0.008,100]	^100 (Ref.52)		99.70 (Ref.54)
	Trichloroethylene	1	[50,7,0.003,100]	90.00-99.99 (Ref.52)	^100 (Ref.4)	99.90 (Ref.54)
						98.00-100 (In-house Data)
	Carbon Tetrachloride	1	[50,6,0.006,100]	moderate (Ref.1)		
	Perchloroethylene					
	Ethylene Dibromide	1				
Aryl Halides	Dichlorobenzene	1	[50,8,0.007,96]			70.00-90.00 (Ref.52)
Phenols	Phenols	5	<23.00 (Ref.2)	0.40-61.00 (P&P,Ref.10)	95.00 (Ref.4)	
				Ineffective (Ref.55)		
				Strippable (Ref.52)		
	Cresols	5	<78.00 (Ref.2)		69.00-100 (Ref.4)	
	Pentachlorophenol	3	<98.00 (Ref.2)		0 (Ref.4)	
Oxygenated Compounds	Propylene Oxide	2				
	Vinyl Acetate	1				
Mixtures & Miscellaneous	Hydrazine	1				
	Carbon Disulfide					
	Turpentine					
	2,4 Toluene Diisocyanate					
	Naphtha					
	Tall Oil					

Notes :

a) Strippability by air or steam (Reference 53)
   1) Very easily stripped
   2) Easily stripped
   3) Intermediate
   4) Difficult
   5) Very difficult
   6) Cannot be stripped

b) [Outlet Conc.(ppb), number of tray, steam-feed ratio(w/w), removal(%)] (Reference 2)
   Results of a theoretical study

c) P&P = Pulp & Paper Industry

d) RCC = Resources Conservation Co.

e) All data except as noted were extracted from studies pertaining to organic priority pollutants, ie. industrial wastewaters and hazardous wastes etc.

Two theoretical studies have been identified that are concerned primarily with the treatability of organic pollutants (References 1, 2). These analyses apply the principles of thermodynamics and pollutant's physical properties to determine the feasibility of steam stripping. The conclusions from these studies are that steam stripping can be effective in treating a large number of the organic priority pollutants from wastewaters to effluent concentrations ranging from 50 ppb to 1 ppb.

Effluent concentrations of 10 ppb - 1ppb for condensed aromatic pollutants, 1 ppb for poly-chlorinated biphenyls (PCB's) and hexachloro-cyclohexanes (BHC's), and 4 ppb and 6 ppb for butyl benzyl phthalate and di-n-octyl phthalate respectively are attainable because of their limited solubilities and high activity coefficients in water (Reference 2). Steam stripping is extremely effective in treating a large number of priority pollutants exhibiting high activity coefficients and moderate vapour pressures. It resembles the separation of insoluble light gases (Reference 2).

It is generally difficult to efficiently remove phenolic compounds from wastewaters by steam stripping. A theoretical study (Reference 2) shows that the removal efficiency is not sufficient to consistently meet an effluent concentration of 50 ppb, and the simulated removal efficiency attained without reflux is less than 23%. This is consistent with another study (Reference 53) which rated the strippability of phenol as "very difficult".

Another reference (Reference 4), however, reported the contrary, phenols remove efficiency of 95% was attained with a stripping medium containing air and steam. RCC also has data supporting the treatability of certain phenolic compounds with stream stripping. These conflicting reports suggest the possibility that steam stripping may be applicable to certain specific types of phenolic compounds, and not necessarily across-the-board to all phenols.

The same theoretical study as referred to previously (Reference 2) also concludes that low molecular weight aliphatic-chain phthalate esters and benzidines are non-treatable by steam stripping. High molecular weight ethers are either non-treatable or difficult to treat to achieve a high degree of removal by steam stripping.

As indicated in Table 2-1 it can be readily identified that the pollutants that can be easily stripped include low molecular weight alcohols, aliphatic aromatic hydrocarbons, alkyl halides and aryl halides.

2.5 PHYSICAL CONSTANTS OF CANDIDATE COMPOUNDS

The molecular weight, vapour pressure, Henry's Law constant, solubility, boiling point and activity coefficient (References 1, 2, 41, 49, 51, 59) for each of the 48 candidate compounds identified by EETD are presented in Table 2-2 (with the exception of latex). Henry's Law constants are presented as listed in Reference 41, whereas equilibrium constants and activity coefficients are presented only as listed in Reference 2.

TABLE 2 - 2

PHYSICAL PROPERTIES OF CANDIDATE COMPOUNDS

CHEMICAL FAMILY	CANDIDATE COMPOUND	MOLECULAR WEIGHT	VAPOR PRESSURE (kPa)	at TEMP. (C)	HENRY'S LAW CONSTANT @ 25C (atm-m3/mole)	SOLUBILITY (g/100g)	BOILING POINT (C)	ACTIVITY COEFFICIENT	VAPOUR-LIQUID EQU. CONSTANT K	COMMENT
Aldehydes	Formaldehyde	30	100.00	-19.5		miscible	-20			
	Butyraldehyde	72	9.40	20		7.1	75			
Ketones	Acetone	58.08	51.50	100	6.80E-06	230	56.2			
	Methyl Ethyl Ketone	72.11	10.30	20	2.40E-05	35.3	79.6			
	Methyl Isobutyl Ketone	100.16	1.30	30	1.32E-04	1.9	119			
Alcohols	Methanol	32.04	21.20	30	1.10E-06	440	64.5			
	Ethanol	46.1	10.00	30		miscible	78.4			
	Isopropanol	60.1	7.60	30		miscible	82.4			
	Butanol	74.12	1.3-7.5	30	7.00E-06	9.1	83-118			
	2-Ethyl Hexanol	130.2	0.13	33		0.1	179-185			
	Ethylene Glycol	62.07	0.03	30		miscible	198			Less volatile than water
	Propylene Glycol	76.1	0.02	20		miscible	180-210			Less volatile than water
Alkanes	n-Hexane	86.17	20.20	25	1.23E+00	0.00095	68.7			
Carboxylic Acids	Formic Acid	46	7.00	30		miscible	100.8			
	Acetic Acid	60.1	2.65	30		miscible	118			Less volatile than water
Amines	Methylamine	31-59	192-313	20		miscible	-6.5-2.9			
	Ethanolamine	61.1	0.80	60		miscible	171			Less volatile than water
	Morpholine	87.1	1.80	30		miscible	128			Less volatile than water
Dienes	1,3 Butadiene	54.1	281.00	25	7.38E-02	0.074	-4.4			
Unsaturated Carbonyl Compounds	Acrylonitrile	53	196.00	100		7.3	77.4	17.5-14.3	30.75	
	Methyl Methacrylate	100.1	6.50	30		1.5	100			
Alicyclic Hydrocarbons	Cyclohexane	84.16	12.70	25	1.78E-01	0.005	80.7			
Aromatic Hydrocarbons	Benzene	78.11	187.00	100	5.55E-03	0.18	80.1	654.2-665.7	1215	
	Toluene	92.14	74.70	100	6.64E-03	0.05	110.6			
	Styrene	104.2	1.30	30		0.04	145.2			
	Ethyl Benzene	106.2	33.90	100	7.90E-03	0.01	136.2			
	Isopropyl Benzene	120.2	0.61	25	1.29E-03	0.005	154.2			
Alkyl Halides	Vinyl Chloride	62.5	3240.00	100	2.30E-02	0.25	-14	145	4627	
	Methylene Chloride	84.93	600.00	100	3.39E-03	1.67	40	227-159	941.4	
	Ethylene Dichloride	98.96	14.00	30	5.32E-03	0.87	83.5			
	Chloroform	119.39	307.00	100	3.39E-03	0.93	61.2			
	Trichloroethylene	133.41	150.00	100	4.92E-03	0.11	74.1	1131	1674	
	Carbon Tetrachloride	153.83	200.00	100	2.13E-02	0.05	76.7	1654	3264	
	Perchloroethylene	165.83	6.00	40		0.015	121			
	Ethylene Dibromide	187.9	2.20	30	1.20E-03	0.431	131			

TABLE 2 - 2 (Cont'd)

PHYSICAL PROPERTIES OF CANDIDATE COMPOUNDS

CHEMICAL FAMILY	CANDIDATE COMPOUND	MOLECULAR WEIGHT	VAPOR PRESSURE (kPa)	at TEMP. (C)	HENRY'S LAW CONSTANT @ 25C (atm-m3/mole)	SOLUBILITY (g/100g)	BOILING POINT (C)	ACTIVITY COEFFICIENT	K	COMMENT
Aryl Halides	Dichlorobezene	147.01	10.00	100	1.94E-03	0.015	180.5	5392-14200	429.2-1364	
Phenols	Phenols	94.1	5.30	100		8.66	182	43	2.2	
	Cresols	108.1	0.66	76		2.4-3.1	191-202			
	Pentachlorophenol	266.4	0.03	100	1.40E-03	low		31500	10.4	Decomposes at 310C
Oxygenated Compounds	Propylene Oxide	58.1	53.00	18		65	34			
	Vinyl Acetate	86.1	15.30	25		2.5	72			
Mixtures & Miscellaneous	Hydrazine	32.1	3.30	30		miscible	113.5			Less volatile than water
	Carbon Disulfide	76.1	57.00	30		0.23	46.3			
	Turpentine	136+/-	0.66	25		low	154-170	1569	1156	
	2,4 Toluene Diisocyanate	174.2	0.13	80		reacts	251			
	Naphtha	varies	10.00	38		low	30-202			
	Tall Oil	varies				low	high			

The relative volatility of organic compounds in water is a complex property involving water solubility, boiling point, vapor pressure and tendency to form hydrogen bonding. Organic compounds that are ionized are not volatile. For instance, at alkaline pH, phenolic compounds would tend to ionize to the negatively charged phenolate ion and would not be removed by steam stripping. In general, steam volatility increases as boiling point, water solubility and hydrogen bonding decrease.

As the molecular weight of a hydrocarbon increases, the decrease in vapor pressure is normally smaller than the increase in activity coefficient in water. Thus even many low vapour pressure compounds may be successfully steam stripped.

2.6 PRELIMINARY ASSESSMENT OF STEAM STRIPPING OF CANDIDATE COMPOUNDS

At this stage some comments may be made on the feasibility of steam stripping the compounds identified by EETD. They result from the range of physical properties of the materials being considered and, with a few exceptions, have the effect of imposing constraints or ancillary requirements on the system.

Solubility The list of candidate compounds contains both those with low and high solubility in water. In order to obtain a concentrated overhead product with a soluble contaminant, it will be necessary to use a feed point near the middle of the column and to use a different reflux/overhead control strategy than for an insoluble contaminant.

Compounds which are completely miscible in water and which are less volatile than water present a practical difficulty in steam distillation. Normally the contaminants are recovered as a small overhead stream. However, when water is the more volatile component, the contaminant will concentrate in the bottoms stream. While technically possible, the variation in equipment sizes make treatment of such compounds impractical. Examples include ethylene and propylene glycol, ethanolamine and the like.

pH Related to solubility is the need to ensure that organic acids are in the un-ionized form. Facilities for lowering the pH with mineral acid would be required to ensure effective stripping of compounds such as formic acid.

Flammability Many compounds being considered are highly volatile and flammable. Vapor control and electrical design will need to reflect this hazard.

Toxicity Several compounds being considered are highly toxic. The facilities will have to be designed to protect both the operators and the public.

Polymerization Several compounds being considered are prone to free radical or ionic polymerization. Even if a reaction inhibitor is present in the original feed, it may be removed in the stripper. Fouling with polymer is inconvenient and runaway exothermic polymerization is a serious hazard.

If compounds such as styrene, 1,3 butudiene and vinyl chloride are to remain on the list of candidate compounds, consideration will have to be given to addition of a suitable reaction inhibitor.

2.7 COMPUTER PROCESS DESIGN

Two computerized process design programs are readily available for process design and equipment sizing during this study. One is PROCESS, a Simulation Sciences program installed on one of CH2M HILL's mainframe computers. The other is VACAD, a program developed and owned by RCC for development of AquaDetox steam stripping designs.

PROCESS is capable of modelling many unit processes in any desired configuration. This flexibility requires that the input files specify the equipment configuration as well as the process boundary conditions. PROCESS has a large built- in library of component physical properties but only a limited amount of data on water - chemical systems. Manual calculation of mass transfer coefficients and liquid-liquid activity coefficients is required.

VACAD is a much smaller program designed specifically for steam stripping systems. Only the process boundary conditions and component physical properties are required.

Manual input of heat transfer coefficients and phase separation times are required. The program calculates mass transfer coefficients, all equipment sizes and a complete heat and material balance.

The main differences are that VACAD is specifically designed to size a steam stripper system whereas PROCESS is designed to model the operation of a user-defined and sized process system. We believe that using VACAD will produce the desired data with less time and effort and therefore propose its use in the next phase of this study.

2.8 PRELIMINARY CONCLUSION AND RECOMMENDATIONS

A review of published operating results as well as a preliminary assessment of the physical properties of the candidate compounds shows steam stripping to be a promising technique in removing most of these pollutants from wastewaters. Other compounds with physical properties similar to those of the candidate compounds are also capable of being steam stripped. The well established design procedures for gas-liquid mass transfer increase the level of confidence in applying this process to untested contaminants.

The following were recommended:

1. On the basis of encouraging results from a number of sources we recommended continuing the feasibility study as originally planned.

2. We recommended that the following compounds be deleted from the list of candidate pollutants:

- All compounds completely miscible in and less volatile than water:

- ethylene glycol
- propylene glycol
- acetic acid
- ethanolamine
- morpholine
- hydrazine

o Latex, as it is an emulsion of solid rubber in water.

o 2, 4, toluene diisocyanate, as it reacts with water.

3. Although poor strippability of phenol and substituted phenols has been reported, we recommended that they be retained on the list of candidate pollutants as certain phenolic compounds have been proved to be treatable.

2.9 DATA SHEETS

Data Sheet
Project No: T023706.A0

Pulp & Paper
Reference 35

I. SOURCE: Air Stripping Kraft Foul Condensate to Remove Methanol

II. AUTHORS: B. Blackwell, F. Murray, W. Oldham

III. LOCATION: University of British Columbia
Vancouver

IV. TIME OF EXPERIMENTATION: 1979

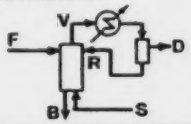
V. PRETREATMENT:

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
Methanol				90	

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = 1/0.5= 2 (mol/mol) Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER GAS TYPE: Saturated Air

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	71			
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN

SIZE	CONTACTING MEDIUM: PACKING	TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) =	Packing Ht. (m) = 9.15	No. =	Packing was separated every 0.61m for liquid redistribution.
Dia. (m) = 0.1			
Matl. = Plexiglass	Type = 0.64cm Intalox Saddle	Type =	
No. =	Matl. = Ceramic	Matl. =	
	HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS: Column feeds comprised of foul condensates from kraft mill.
Poor methanol removal during ambient air stripping was partly due to evaporative cooling, this can be counteracted by increasing the air enthalpy of the stripping gas by adding steam to the feed air.

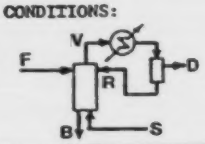
I.	SOURCE: Treatment of Sulfite Evaporator Condensates for Recovery of Volatile Compounds					
II.	AUTHORS: K.W. Baierl, B.F. Lueck, A.J. Wiley					
III.	LOCATION: Appleton Mill of Consolidated Paper	V.	PRETREATMENT:			
IV.	TIME OF EXPERIMENTATION: 1972					

VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit)					

Has been demonstrated capable of removing sulphur dioxide, methanol, and furfaral from sulfite mill condensates recovered from backwashing of the evaporator. A vapor containing 85+% w of SO_2 was produced. The vapor phase also contained methanol and furfural. The product stream contained acetic acid and traces of furfural.

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER / GAS — TYPE: Steam

(C) TEMPERATURE (°C)	WASTEWATER INLET	WASTEWATER OUTLET	GAS INLET	GAS OUTLET

(D) PRESSURE (kPa)	WASTEWATER INLET	WASTEWATER OUTLET	GAS INLET	GAS OUTLET
	Atmospheric			

(E) COLUMN	SIZE	CONTACTING MEDIUM: PACKING	CONTACTING MEDIUM: TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) =	Packing Ht. (m) =	No. =	No dimensions given.
	Dia. (m) =			
	Matl. =	Type =	Type =	
	No. =	Matl. =	Matl. =	
		HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

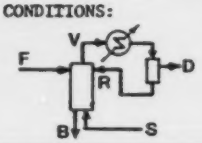
IV. COMMENTS:

I.	SOURCE: Steam Savings and BOD Reduction Using Vapor Compression, Liquor Evaporation, and Distillation.					
II.	AUTHORS: H. Beder, L. Madrid					
III.	LOCATION: Weyerhauser's Weyco Mill, Springfield, Oregon		V.	PRETREATMENT:		
IV.	TIME OF INSTALLATION: 1976					

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
Methanol				98	← Overhead= 15-20% Methanol
BOD				90	
COD				83	

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = 100/15 = 6.67 (w/w) Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER / GAS TYPE: Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
(D) PRESSURE (kPa)	Vacuum			

(E) COLUMN	SIZE	CONTACTING PACKING	CONTACTING TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) = 3	Packing Ht. (m) =	No. = 18	
	Dia. (m) =			
	Matl. =	Type =	Type = Glitch Ballast	
	No. =	Matl. =	Matl. =	
		HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

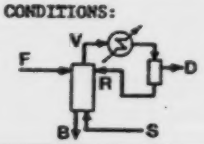
IV. COMMENTS: Column feeds comprise of ME evaporator, surface condenser condensates, digestor condensates, and VCE vent steam.
- VCE (Vapor Recompression Evaporator) is used for pre-evaporation of black liquor.
- Installed facility currently in operation.

I.	SOURCE: Stripping-Incineration System Cuts TRS Emissions at Cornwall.					
II.	AUTHORS: B. Rowbottom, G. Wheeler					
III.	LOCATION: Domtar Fine Papers, Cornwall, Ontario		V.	PRETREATMENT:		
IV.	TIME OF INSTALLATION: 1974					

VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit) See Attached List					

VII. OPERATING CONDITIONS:

(A) FLOW



F = 6.31 L/S B = S = Others:

R = V = D =

L/G = 100/10=10 (w/w) Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER | GAS TYPE: Steam

	INLET	OUTLET	INLET	OUTLET
(C) TEMPERATURE (°C)	96			
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN

SIZE	CONTACTING MEDIUM: PACKING	CONTACTING MEDIUM: TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) = 5.49 Dia. (m) = 0.91 Matl. = No. = 1	Packing Ht. (m) = 5.08 cm Type = Pall ring Matl. = SS 316 HTU =	No. = Type = Matl. = η =	Rectifying section: Ø = 0.91m Packing ht= 2.44 m

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS:
- Column feed comprises of digester and evaporator foul condensate.
- Installed facility currently in operation.

SOURCE : Stripping - Incineration System Cuts TRS Emissions at Cornwall

WASTEWATER CONTAMINANTS	INLET (mg/L) PRIOR TO PRETREATMENT	INLET (mg/L) AFTER PRETREATMENT	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
Sulfide	30		< 0.1	> 97	
CH_3SH	86		11	85 - 90	
$(CH_3)_2S$	240		< 0.1	> 99.96	
$(CH_3)_2S_2$	117		2.8	97.61	
Methanol	5350		2680	49.91	*
Ethanol	170		< 0.1	> 99.94	
Acetone	51		< 0.1	> 99.81	
MEK	24		< 0.1	> 99.58	

MEK = Methyl Ethyl Ketone
Data recorded for steam ratio of 10% (w/w)

* 20% steam required for 90% removal

I. SOURCE: Nekoosa Cleans Condensates with Steam Distillation

II. AUTHORS: T. Burgess, D. Voigt

III. LOCATION: Nekoosa, Wisconsin

IV. TIME OF INSTALLATION: 1976

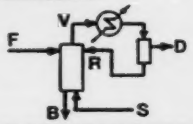
V. PRETREATMENT:

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
BOD	2945		356	85	
Methanol	1104		122	89	
Sulfide	85		12	86	
TRS				99	

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER GAS TYPE: Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN

SIZE	CONTACTING MEDIUM: PACKING	CONTACTING MEDIUM: TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) = 18.3	Packing Ht. (m) =	No. =	
Dia. (m) = 2.44			
Matl. = SS 304	Type =	Type = SS 304	
No. =	Matl. =	Matl. =	
	HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

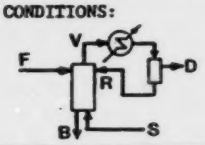
IV. COMMENTS:
- Column feed comprises of condensates collected from the digester blow gases, turpentine recovery operation and black liquor evaporators.
- Installed facility currently in operation.

I.	SOURCE: Steam Stripping of Foul Condensates at Great Lakes					
II.	AUTHORS: D. A. Donavan, E. M. Yemchuk, G. H. Valiquette					
III.	LOCATION: The Great Lakes Forest Products, Thunder Bay, Ontario		V.	PRETREATMENT:		
IV.	TIME OF INSTALLATION: 1977					

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit) See Attached List					

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER / GAS — TYPE: Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN	SIZE	CONTACTING PACKING	CONTACTING TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) = 3.66 Dia. (m) = 1.98 Matl. = SS304 No. = 1	Packing Ht. (m) = Type = 5.08cm Pall Ring Matl. = SS304 HTU =	No. = Type = Matl. = η =	A second stage stripping column with integrals rectifier . Type SS316 construction . Stripping = 1.07mØ x 3.66m H . Rectifying = 1.37mØ x 3.66m H . Type SS304 50.8mm pall rings.

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS:
Installed facility currently in operation

SOURCE : Steam Stripping of Foul Condensates at Great Lakes

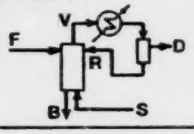
WASTEWATER CONTAMINANTS	INLET (mg/L) PRIOR TO PRETREATMENT	INLET (mg/L) AFTER PRETREATMENT	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
A: 1st stage	BOD, methanol			86, 91	L/G: 100/27 (w/w)
2nd stage	BOD, methanol			50, 67	L/G: 100/22 (w/w)
Overall	BOD, methanol			75, 88	
B: 1st stage	BOD, methanol			82, 88	L/G: 100/28 (w/w)
2nd stage	BOD, methanol			39, 62	L/G: 100/24 (w/w)
Overall	BOD, methanol			65, 81	
C: 1st stage	BOD, methanol				
2nd stage	BOD, methanol, TRS			90, 90, 98	L/G: 100/22 (w/w)
Overall	BOD, methanol				

I.	SOURCE: Steam Stripping of Kraft Mill Condensates					
II.	AUTHORS: L. Dev, P.W. Kelso					
III.	LOCATION: Weyerhaeuser's Longview Mill		V.	PRETREATMENT:		
IV.	TIME OF INSTALLATION: 1978					

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
BOD				85	

VII. OPERATING CONDITIONS:

(A) FLOW



F = 8600kg/h B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION

(C) TEMPERATURE (°C)	WASTEWATER INLET	WASTEWATER OUTLET	GAS INLET	GAS OUTLET
(D) PRESSURE (kPa)	Atmospheric			

GAS TYPE: Steam

(E) COLUMN SIZE	CONTACTING MEDIUM: PACKING	CONTACTING MEDIUM: TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) = 16.5	Packing Ht. (m) =	No. = 19 trays with 537 valves per tray	. Design column efficiency = 50% . Tray spacing = 0.61m . Feed locations are above trays 7, 13, 16
Dia. (m) = 2.29			. Pressure drop = 10KPa
Matl. = SS304L	Type =	Type = Valve	. Vertical thermosiphon reboiler
No. = 1	Matl. =	Matl. = SS340L	. Design was based on methanol-water solution characteristics
	HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS:

. Column feeds comprise of ME evaporator & digester condensates & VCE vent steam (Contains BOD)
. VCE (Vapor recompression evaporator) is used for pre-evaporation of black liquor
. Installed facility currently in operation

I. SOURCE: Elimination of Impurities Contained in Kraft Mill Condensates

II. AUTHORS: Instytut Celulozowo-Papierniczy, Poland

III. LOCATION: Poland

IV. TIME OF EXPERIMENTATION: 1978

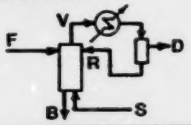
V. PRETREATMENT:

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
Methanol				70	

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER / GAS TYPE: Steam

(C) TEMPERATURE (°C)	WASTEWATER INLET	WASTEWATER OUTLET	GAS INLET	GAS OUTLET

(D) PRESSURE (kPa)	WASTEWATER INLET	WASTEWATER OUTLET	GAS INLET	GAS OUTLET
	Atmospheric			

(E) COLUMN	SIZE	CONTACTING MEDIUM: PACKING	CONTACTING MEDIUM: TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) =	Packing Ht. (m) =	No. =	
	Dia. (m) =			
	Matl. = Vigreux	Type =	Type =	
	No. = 1	Matl. =	Matl. =	
		HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS: Column feed was condensates from digester relief gases and from a multiple-effect evaporator. The condensates were treated seperately for maximum purification efficiency.

I. SOURCE: CH2M Hill Industrial Client - Air Stripping

II. AUTHORS: B. Byers

III. LOCATION: Portland, Oregon area

IV. TIME OF EXPERIMENTATION: 3/87

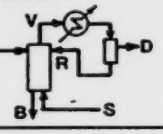
V. PRETREATMENT: None

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
Trichloroethylene	1-10	N/A	0.03-0.005	98-99.99	
Tetrachloroethylene	0.2-1.2	N/A	0.015-0.005	98-99.99	
1,1,1 Trichloroethylene	0.2-1.2	N/A	0.17- 0.005	96-99.99	
Trans 1,2 Dichloroethylene	1-3	N/A	≤0.03	≥ 99	
1,2 Dichloroethane	0.1	N/A	≤0.01	≥ 90	
Acetone	~1.0	N/A	<0.01	> 99	

VII. OPERATING CONDITIONS:

(A) FLOW (L/min)



F = 20-80 B = 20-80 S = 700-3000 Others:

R = N/A V = 700-3000

L/G = 0.007 (v/v) to 0.03 (v/v)

Feed Stage = Top

(B) FLOW CONFIGURATION: WASTEWATER: Contaminated Groundwater; GAS TYPE: Air

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	16-40	16-40	15-25	15-25
(D) PRESSURE (kPa)	100	100	100	100

(E) COLUMN

SIZE	CONTACTING MEDIUM PACKING	CONTACTING MEDIUM TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) = 12	Packing Ht. (m) = 6-9	No. =	
Dia. (m) = 0.3	Type = #1A Cascade mini rings(1)	Type =	
Matl. = coated steel	Matl. = Polypropylene	Matl. =	
No. = 1	HTU = 1-2m	ℓ =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER: To industrial wastewater treatment plant.

(B) DECANT OVERHEAD ORGANICS: N/A

IV. COMMENTS:

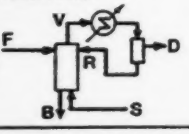
(1) Cascade mini rings are slotted ring type packing, product of Glitsch, Inc.

I.	SOURCE: CH2M Hill Industrial Client - Air Stripping					
II.	AUTHORS: B. Byers					
III.	LOCATION: Corvallis, Oregon		V.	PRETREATMENT: None		
IV.	TIME OF EXPERIMENTATION: 1/87 - 3/87					

VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit)					
	Trichloroethylene	0.2 - 1.5	N/A	0.002-0.005	98.5 - 99.9	

VII. OPERATING CONDITIONS:

(A) FLOW (L/min)



F = 80 B = 80 S = 7500 (air) Others:

R = N/A V = 7500 (air) D = N/A

L/G = 0.01 (v/v)

Feed Stage = Top

(B) FLOW CONFIGURATION

WASTEWATER	GAS TYPE: Air
Plant wastewater	

(C) TEMPERATURE (°C)	WASTEWATER INLET	WASTEWATER OUTLET	GAS INLET	GAS OUTLET
	16	16	16	16
(D) PRESSURE (kPa)	100	100	100	100

(E) COLUMN	SIZE	CONTACTING MEDIUM PACKING	CONTACTING MEDIUM TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) = 6.4 Dia. (m) = 0.46 Matl. = FRP No. = 1	Packing Ht. (m) = 4.6 Type = 2.5 cm Nor-pac (1) Matl. = Polypropylene HTU = 0.6 m	No. = Type = Matl. = η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER: To industrial wastewater treatment plant.

(B) DECANT OVERHEAD ORGANICS: N/A

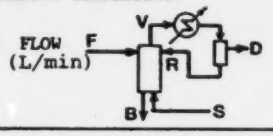
IV. COMMENTS:

(1) Nor-pac is a product of Croll-Reynolds - basically a slotted ring

Data Sheet
Project No: T023706.AO

In-house Data

I.	SOURCE: Data from Savannah River Plant - Telephone Conversation					
II.	AUTHORS: John L. Steele, Dupont from Bill Byers, CH2M Hill					
III.	LOCATION: Aiken, South Carolina		V.	PRETREATMENT: None		
IV.	TIME OF EXPERIMENTATION: 1984					
VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit)					
	Trichloroethylene	~ 150	N/A	<0.001	> 99.999	
	Tetrachloroethylene	~ 150	N/A	<0.001	> 99.999	

VII.	OPERATING CONDITIONS:	F = 200	B = 200	S = 10,000	Others:	
	(A) FLOW (L/min) 	R = N/A	V = 10,000			
		L/G = 0.02 (v/v)		Feed Stage = Top		
	(B) FLOW CONFIGURATION	WASTEWATER: Contaminated groundwater		GAS TYPE: Air		
	(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET	
	(D) PRESSURE (kPa)	100	100	100	100	

(E) COLUMN	SIZE	CONTACTING PACKING	MEDIUM TRAY	SPECIAL FEATURES OF PROCESS	
	Ht. (m) = ~15	Packing Ht. (m) = 9	No. =		
	Dia. (m) = 0.5				
	Matl. = SS	Type = 2.5cm flexi-rings	Type =		
	No. = 1	Matl. = PVC	Matl. =		
		HTU = 1m	η =		

VIII.	WASTE REMOVAL AND DISPOSAL METHODS:	
	(A) TREATED WATER:	Unknown
	(B) DECANT OVERHEAD ORGANICS:	N/A
IV.	COMMENTS:	

CG/MISC/10 (917)

Data Sheet
Project No: T023706.AO

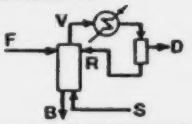
Reference 54

I.	SOURCE: Gilson Road Hazardous Waste Site Pilot Plant Treatment Study					
II.	AUTHORS: Roy F. Weston, Inc. Concord, New Hampshire & Env. Eng. Consultants, Stillwater, Oklahoma					
III.	LOCATION: New Hampshire		V.	PRETREATMENT: None		
IV.	TIME OF EXPERIMENTATION: 1982					

VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit) See Attached List					

VII. OPERATING CONDITIONS:

(A) FLOW



F = B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION — WASTEWATER — GAS — TYPE: Air & Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	71			
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN	SIZE	CONTACTING MEDIUM PACKING	TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) =	Packing Ht. (m) =	No. =	Details on column was presented in a separate report which was not obtained for this study.
	Dia. (m) =			
	Matl. =	Type =	Type =	Condenser temp. = 15.5°C
	No. = 1	Matl. =	Matl. =	
		HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS: Column feed was contaminated water near Gilson Road Hazardous Waste Site in Nashua, New Hampshire.

SOURCE : Gilson Road Hazardous Waste Site Pilot Plant Treatment Study

1) Air Stripping

L/G = 1/100 = 0.01 (v/v)

WASTEWATER CONTAMINANTS	INLET (mg/L) PRIOR TO PRETREATMENT	AFTER PRETREATMENT	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
Methanol	380			85.4	
Ethanol	58			84.6	
Acetone	120			85.4	
1-Propanol	7			71.4	
2-Propanol	280			72.0	
THF	170			90.3	
MEK	37			88.9	
Methylene Chloride	8.4			99.6	
Chloroform	1.3			99.7	
1,1,1-Trichloroethane	0.45			99.94	
Trichloroethylene	0.73			99.91	
Tetrachloroethylene	17			99.95	

THF = Tetrahydrofuran
MEK = Methyl Ethyl Ketone

2) Steam Stripping

Run No.	Reboiler Temp.(F)	Reflux Vap. Temp. (F)	Percent Evaporated	Reflux Ratio	Press. Drop (mmHg)	Organics Conc.(%) Distillate	Bottom
1003	215	211	55.7	13.33	6.4		
1004	214	211	24.5	13.33	3.7		
1006	213	184	1.4	30	0.6	49.47	2.9E-5
1007	212	197	1.6	20	0.6	24.97	1.8E-5
1008	213	207	2.9	10	0.6	13.05	9.7E-6
1009	213	208	2.7	10	1.3	9.99	6.6E-6
1010	213	208	4.5	5	1.3	9.09	5.3E-6
1011	213	210	6.7	2	1.25	7.24	1.8E-5
1012	213	193	3.8	20	1.35	29.96	8.3E-6
1013	213	204	2.8	10	1.3	11.82	8.3E-6

Data Sheet
Project No: T023706.AO

Reference 48

I. SOURCE: Pilot Testing & Design of a High Temperature Air Stripping System for MEK Removal

II. AUTHORS: K. M. Sullivan, F. Lenzo, T. Johnson

III. LOCATION: New York State

IV. TIME OF EXPERIMENTATION: 1984 - 1985

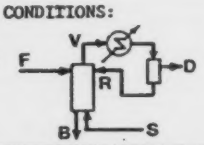
V. PRETREATMENT:

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
Methyl Ethyl Ketone	1000		< 0.05	99.7	

VII. OPERATING CONDITIONS:

(A) FLOW



F = 407 L/min/m^2 B = S = Others:
R = V = D =

L/G = 1/150 = 0.0067 (v/v) Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER GAS TYPE: Air

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	71			
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN

SIZE	CONTACTING MEDIUM PACKING	CONTACTING MEDIUM TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) = 6.4	Packing Ht. (m) = 4.6	No. =	. Steel piping . Sample taps located at 1.5m intervals
Dia. (m) = 0.254			
Matl. = Aluminum	Type = 3.8cm Pall ring	Type =	
No. = 1	Matl. = Polypropylene	Matl. =	
	HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS:
Portable packed column pilot unit successfully used in 25 sites.
Testing at over 25 sites showed that removal efficiencies do not vary greatly with inlet concentration.

Data Sheet
Project No: T023706.AO

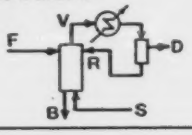
Reference 4

I.	SOURCE: Contaminated Groundwater Treatability — A Case Study					
II.	AUTHORS: E. L. Stover, D.F. Kincannon					
III.	LOCATION: Oklohoma		V.	PRETREATMENT:		
IV.	TIME OF EXPERIMENTATION: 1983					

VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit)	6	-	-	-	-
	See Attached List					

VII. OPERATING CONDITIONS:

(A) FLOW



F = 0.13 L/min B = S = 0.11 L/s (0.25cfm) Air Others: Waterflow (L/min) (Before Steam): 0.13 (After Steam) : 0.17

R = 0 V = D =

L/G = 0.13/0.04 = 3.25 (w) Feed Stage =

(B) FLOW CONFIGURATION

WASTEWATER GAS TYPE: Steam & Air

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	23	86	Air (24°C)	Air (35°C)
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN	SIZE	CONTACTING MEDIUM PACKING	TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) = 1.22	Packing Ht. (m) = 0.66	No. =	Air is introduced with Steam and flowed countercurrently to the water.
	Dia. (m) = 0.079			
	Matl. = Glass	Type = 0.7 cm Raschig	Type =	
	No. = 1	Matl. = Glass	Matl. =	
		HTU =	ℏ =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS: Pretreatment for metal removal was required to prevent clogging of the media. Above data was gathered from Run 2-representing the most complete data.

SOURCE : Contaminated Groundwater Treatability - A Case Study

WASTEWATER CONTAMINANTS	INLET (mg/L) PRIOR TO PRETREATMENT	INLET (mg/L) AFTER PRETREATMENT	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
Benzene	69		*	100	
Trichloroethylene	338		*	100	
MIK	76		*	100	
Toluene	92		*	100	
Ethylbenzene	24		*	100	
1,4 Dichlorobenzene	0.35		0.17	51	
1,2 Dichlorobenzene	0.05		*	100	
Phenol	3.7		0.20	95	
o-Cresol	0.8		0.25	69	
m-Cresol	2.2		*	100	
Pentachlorophenol	0.4		0.40	0	
TOC	4000		1700	< 32.5	Diluted effluent

MIK = Methyl Isobutyl Ketone

* Non-detectable

I. SOURCE: CH2M Hill Process Design - Synfuels Facility

II. AUTHORS: B. Byers, J. Downing

III. LOCATION: Confidential

IV. TIME OF EXPERIMENTATION:

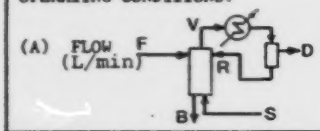
V. PRETREATMENT:

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
Ammonia (Free)	1000	N/A		99 (2)	
TOC (1)	250	N/A		75 (2)	

VII. OPERATING CONDITIONS:

(A) FLOW (L/min)



F = 1400 B = 1400 S = 16000 kg/h Others:

R = V = 13600 kg/h D = 13600 kg/h

L/G = 8.4 (w/w) Feed Stage = Top

(B) FLOW CONFIGURATION: WASTEWATER: Evaporator Distillate; GAS: TYPE: Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	99	104	127	100
(D) PRESSURE (kPa)	120	120	120	120

(E) COLUMN

SIZE	CONTACTING PACKING	MEDIUM TRAY
Ht. (m) = 17	Packing Ht. (m) = 10	No. =
Dia. (m) = 2		
Matl. = CS	Type = #3 Cascade mini rings	Type =
No. = 1	Matl. = SS	Matl. =
	HTU = 0.7 m	η =

SPECIAL FEATURES OF PROCESS

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER: Industrial wastewater treatment plant.

(B) DECANT OVERHEAD ORGANICS: Process recovery

IV. COMMENTS: (1) TOC is mixture of volatile and semivolatile organic compounds condensed from overhead of upstream multiple effect evaporator.
(2) Design removal efficiencies stripper was not constructed.

I. SOURCE: Physiochemical Treatment Methods for Oil Shale Wastewater; Evaluation as Aids to Bio-oxidation.

II. AUTHORS: B.M. Jones, R.H. Sakaji, C.G. Daughton

III. LOCATION: California

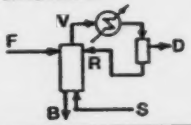
IV. TIME OF EXPERIMENTATION: 1982

V. PRETREATMENT:

VI. WASTEWATER CONTAMINANTS AND MEASUREMENTS:

	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
pH (unit)					
NH_3					
H_2S					
CO_2					

VII. OPERATING CONDITIONS:

(A) FLOW 

F = B = S = Others:

R = V = D =

L/G = Feed Stage =

(B) FLOW CONFIGURATION: WASTEWATER GAS TYPE: Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
(D) PRESSURE (kPa)				

(E) COLUMN

SIZE	CONTACTING MEDIUM PACKING	CONTACTING MEDIUM TRAY	SPECIAL FEATURES OF PROCESS
Ht. (m) = 4.88	Packing Ht. (m) =	No. =	
Dia. (m) = 0.05	Type = 0.64cm Intalox Saddle	Type =	
Matl. = Pyrex glass	Matl. = Ceramic	Matl. =	
No. = 1	HTU =	η =	

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS:

No results presented.

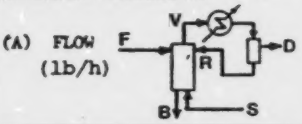
CG/MISC/10 (917)

I.	SOURCE: RCC Confidential Test Program - Steam Stripping					
II.	AUTHORS: D.J. Peterson					
III.	LOCATION: Bellevue, Washington	V.	PRETREATMENT:			
IV.	TIME OF EXPERIMENTATION: 21 Jan. 1986					

VI.	WASTEWATER CONTAMINANTS AND MEASUREMENTS:	INLET (mg/L) Prior to Pretreatment	INLET (mg/L) After Pretreatment	OUTLET (mg/L)	REMOVAL EFFICIENCY (%)	COMMENTS
	pH (unit)	8.2				
	Acetone	358		< 5	> 98	

VII. OPERATING CONDITIONS:

(A) FLOW (lb/h)



F = 10.1 B = 7.9 S = 0 Others:

R = 0 V = 2.2 D = 2.2

L/G = 3.86 (w/w) Feed Stage = 4.85

(B) FLOW CONFIGURATION — WASTEWATER — GAS TYPE: Steam

(C) TEMPERATURE (°C)	INLET	OUTLET	INLET	OUTLET
	70	100		
(D) PRESSURE (kPa)	Atmospheric			

(E) COLUMN	SIZE	CONTACTING MEDIUM PACKING	TRAY	SPECIAL FEATURES OF PROCESS
	Ht. (m) = 2 Dia. (m) = 0.05 Matl. = glass No. = 1	Packing Ht. (m) = 1.8 Type = 0.64cm saddles Matl. = ceramic HTU = 0.5 m maximum	No. = Type = Matl. = η =	Reboiler system utilized

VIII. WASTE REMOVAL AND DISPOSAL METHODS:

(A) TREATED WATER:

(B) DECANT OVERHEAD ORGANICS:

IV. COMMENTS:

Chapter 3
DESIGN BASIS

3.1 DESIGN BASIS

3.1.1 Flow

The plant is to be operated in the 400 to 2,000 L/h range. The design philosophy is to develop a system with maximum possible capacity (within the range specified) within the physical constraints imposed by the transportability of the system. The design maximum flow is taken as 2,000 L/h. From the literature review, the steam-to-feed ratio (by weight) most commonly employed for steam stripping of organic contaminants ranges from 10% to 20%, although ratios as high as 30% have been reported. A value of 20% is used in this study. The overhead waste rate will vary depending on the concentration and solubility of the pollutant being removed. The pump rate is set at a conservative 1.5 percent of feed.

3.1.2 Concentration

Feed concentrations are expected to vary widely and order of magnitude differences are not uncommon in this application. The design system should have flexibility in treating a wide range of feed concentrations. The presence of free hydrocarbons in the feed, however, may seriously impair column operation if they are not decanted and removed prior to entry to the column. For design purposes, the feed concentration has been taken as 1000 mg/L. Since the size of the overhead waste pump is directly

affected by the feed concentration, excess capacity built into the pump will allow the system to handle concentrations in excess of the design value, and to account for disposal of compounds soluble in water.

3.2 SCOPE OF FACILITIES

The scope of the facilities includes the steam stripping column, overhead condenser and subcooler, decanter, feed and reflux preheaters, boiler, feed pump, reflux pump, overhead waste pump, treated effluent pump and associated piping. Equipment outside of the scope includes the feed, treated effluent and overhead waste tanks, boiler feedwater treatment system and other ancillary and support equipment such as electrical generator and boiler fuel supply system. No shelter for the unit is necessary although weatherproof electrical controls and components are required. Total electrical load, boiler fuel, boiler feedwater requirements as well as boiler feedwater quality are specified.

3.3 DESIGN CONCEPT

To facilitate field set-up and operation, simplicity and flexibility are the two design features emphasized. Robustness of the unit is another factor since it must tolerate much handling.

In this application, the concept of pre-packed, bolt-together, modular tower sections; preassembled equipment units and quick-connect fittings is appealing since it facilitates minimum set-up time and minimum handling. As an objective, field set-up

requirements are limited to what could be accomplished in approximately 24 hours by a 3-man crew.

Chapter 4
PROCESS DESCRIPTION

4.1 EVALUATION OF ALTERNATIVES

As a preliminary step in determining the most appropriate system configuration for the mobile steam stripper unit, three alternatives were evaluated. These are illustrated schematically in Figure 4-1 and are described below. At this stage of the study the feed stream was to be routed to the decanter and combined with the reflux stream. This arrangement would eliminate the need to install decanting ability in the feed tank and simplify the process schematics. Separation of these streams would effect only minimal variations on the operation although significant reduction of the decanter size could be realized.

4.1.1 Alternative A - Open Steam

This alternative represents the simplest configuration of the three systems considered. Steam generated from the boiler enters the base of the column, the uncondensed portion exits the column as overhead vapour together with the stripped volatile organics. The stream is then condensed and subcooled. The insoluble liquids in the overhead are separated from the aqueous portion in a decanter and ultimately removed. The remainder of the condensate is preheated with the treated effluent stream before it re-enters the column as reflux. As shown, the feed stream is combined with the reflux in the decanter. Alternatively, it can be preheated with

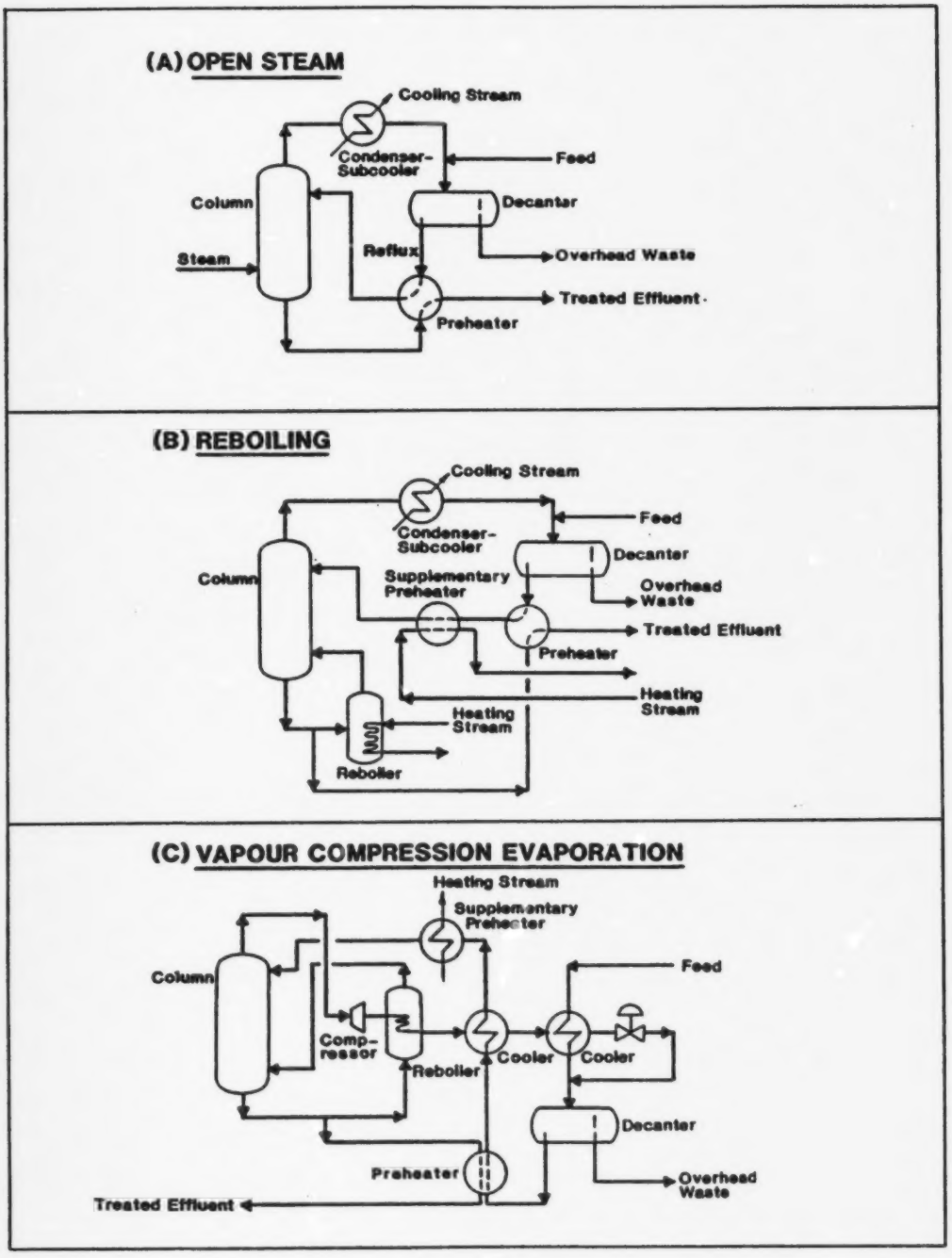


Figure 4-1
MOBILE STEAM STRIPPER UNIT ALTERNATIVES

the treated effluent stream as an independent stream and enters the column either below the reflux point or at the reflux point.

4.1.2 Alternative B - Reboiling

The scheme is essentially the same as the open steam system. The main difference lies in the steam source. For the open steam case, the steam is generated in a boiler whereas for this alternative, the steam is produced from the treated effluent stream with a reboiler.

Supplementary heat is required to preheat both the reflux and the feed streams since the reduced (as explained in the next paragraph) treated effluent steam does not constitute sufficient enthalpy for the heat exchange. The heating medium for this supplementary preheater and the reboiler can be any suitable fluid (steam, glycol, Dowtherm), although steam represents the most easily available and convenient source since it does not preclude disassembly for shipment.

Alternative B represents a closed system with no external steam supply to mix with the process stream since steam is generated within the process. The treated effluent stream is therefore approximately 20% less than that of Alternative A. Steam, if used as the heating medium, can be reused as boiler feedwater with minimum treatment once condensed.

Due to heat exchange limitation imposed by the temperature approach of the exchange streams, not all heat supplied via the heating medium is usable. As a

result, more heat exits the system than Alternative A, which translates to more external steam (if used as the heating medium) requirement. This scheme also permits a higher achievable preheating temperature for the reflux and feed streams as compared to Alternative A. Higher preheating temperature, however, corresponds to higher cooling water requirement since less condensation would occur in the column.

4.1.3 Alternative C - Vapour Compression Evaporation

Alternative C employs the concept of vapour compression evaporation to generate the stripping steam from the treated effluent stream. The overhead vapour is compressed isentropically with a compressor raising simultaneously the vapour's pressure, temperature and enthalpy. This compressed vapour is used to generate the stripping steam in a reboiler and is cooled successively using the reflux and feed as the cooling media. The overhead vapour is condensed and subcooled to prevent flashing upon entering the decanter where the insoluble liquids are removed.

Ideally, the compressor would supply all necessary heat for the system at operating conditions i.e. no external heating source would be required, thereby eliminating the requirement for a boiler and the associated boiler feedwater system. However, the extensive subcooling incorporated to reduce the vapour pressure of the waste organics imposes an additional heat load on the system. Start-up also demands a supplementary heating source be available.

The compressor is less flexible compared to Alternatives A and B to respond to variable feedrate.

4.1.4 Technical and Economic Evaluation

The advantages and disadvantages of each of the three systems considered are listed in Table 4-1.

Technically, Alternative A can be considered the simplest, and perhaps the most flexible option. The major drawback is that the steam is not generated within the process stream, external steam supply and therefore water treatment to boiler feedwater quality is required.

Alternative B is also a highly flexible, although somewhat more complex system. It provides a closed system for both the operating stream and the heating stream, eliminating any direct contact between these two streams. The treated effluent stream is slightly smaller in size that that of Alternative A, thereby reducing the amount of effluent to be disposed of.

Alternative C is technically the least desirable of the three options considered. It is a complex system with relatively low flexibility to respond to off-normal conditions. It also has a high equipment requirement which adversely affects the transportability, assembly, and operationability of the system.

As a result of the foregoing evaluation of the steam stripping system configurations, Alternative A was recommended, and agreed by EETD for more detailed evaluation for the mobile steam stripper unit.

Table 4-1
ADVANTAGES AND DISADVANTAGES OF ALTERNATIVES EVALUATED

	ADVANTAGES	DISADVANTAGES
Alternative A (Open Steam)	o Simplest operation of the three systems evaluated o Equipment requirement is the least	o External boiler feedwater treatment is required.
Alternative B (Reboiling)	o Steam condensate can be reused with minimum treatment o Treated effluent stream is about 20% smaller than that of (A) o Closed system	o More complex operation than (A). o More steam than (A) is likely to be required. o Supplementary heating is required for preheating the feed and reflux streams. o Additional equipment over (A) is required. These include a reboiler and a supplementary reflux/feed preheater.
Alternative C (Vapour Compression Evaporation)	o Treated effluent stream is about 20% smaller than that of (A) o Closed system	o Very complex operation. o External heat source is required for preheating the reflux and feed streams, and for start-up. o Decanter temperature may be higher than the necessary dew point. o The compressor is less flexible to respond to variable feedrate than either (A) or (B). o Additional equipment over (A) is required. These include a reboiler, a compressor, an expansion valve as well as three heat exchangers.

4.2 PHYSICAL/MECHANICAL CONSTRAINTS

The size of the unit in the shipping configuration is limited by the dimensions of the commonly available rental vans. For a 5-ton box van, the dimensions are a 2.13 m x 2.13 m (7 ft x 7 ft) door and inside length from 5.5 m to 6.7 m (18 ft to 22 ft).

Due concern must be given to how the equipment is to be loaded into and unloaded from the van. Sufficient overhead clearance must be provided for in this regard.

An additional constraint on the physical size of the unit could be placed by the legal weight limit. For 5-ton box van, the legal limit is typically 13 000 kg GVW or 7400 kg net.

In view of the field applications the mobile steam stripper is designed for, skid-mounted, pre-assembled equipment modules would facilitate set-up, transportability as well as minimize equipment damage resulting from handling. Quick-connect fittings such as kamlock would minimize set-up time and provide flexibility.

The column is fitted with packing and packing retainers and is divided into several sections that can be lifted into place with a boom-truck or "cherry-picker". The upper limit on the column height is in the vicinity of 9.14 m (30 ft), due to limitation on the reach of a boom-truck.

Stainless steel is considered inadequate to handle either the overhead vapour stream containing hot

chlorinated and organic compounds or the condensed overhead stream with concentrated organics. More exotic materials such as 904 stainless, titanium, Inconel 625 or Hastelloy C-276 may be required for the overhead system, including the overhead condenser, overhead subcooler and decanter.

4.3 PROCESS DESCRIPTION

A flow schematic of the open-steam mobile steam stripper system is presented in Drawing No. P-1. The design maximum feed flow is 2000 L/h (33.3 L/min). Steam-to-feed ratio (weight) is taken as 20% while a conservative value of 1.5% (weight) of feed is used for the overhead waste withdrawal rate.

Saturated steam is generated in the boiler at 95 kPag (14 psig, temperature is 119.8°C or 247.6°F) and is reduced to 35 kPag (5 psig) prior to entry to the column. Volatile components from the countercurrent wastewater are stripped as the steam travels up the 6.10 m (20 ft) packing. The 0.31 m (1 ft) diameter column is 8.38 m (27.5 ft) in overall height and is packed with 25.4 mm (1 inch) stainless steel pall rings. The column is operating at 65% of flood at 20% steam. Treated water will exit the column base.

The column is insulated to prevent excess steam condensation from occurring. The uncondensed steam will exit the column as overhead vapour carrying the volatile contaminants. Due to the lack of available cooling water, the overhead vapour is condensed with a fin-fan air cooler and subsequently subcooled to 15.6°C (60°F) in a plate heat exchanger, with the feed (assuming inlet temperature at 10°C) as the

B-101
BOILER
MFR: BD
CAPACITY: 453 kg/h STEAM
INCLUDE: SKID WITH FEEDWATER TANK (S11), PUMP + STEAM PREHEATER

V-101
STEAM STRIPPING COLUMN
Ø 305 mm (12")
OVERALL HEIGHT: 5486 (216") PACKING HEIGHT: 3660 mm (80") PACKING: 25 mm (1") PALL RING MATERIAL: SS 304

P-101
TREATED EFFLUENT PUMP
FLOW: 9.5 L/min

H-101
OVERHEAD CONDENSER
HEAT DUTY: 230 kW

H-103
OVERHEAD SUBCOOLER
HEAT DUTY: 86 kW
HEAT TRANSFER AREA: 0.4 m²

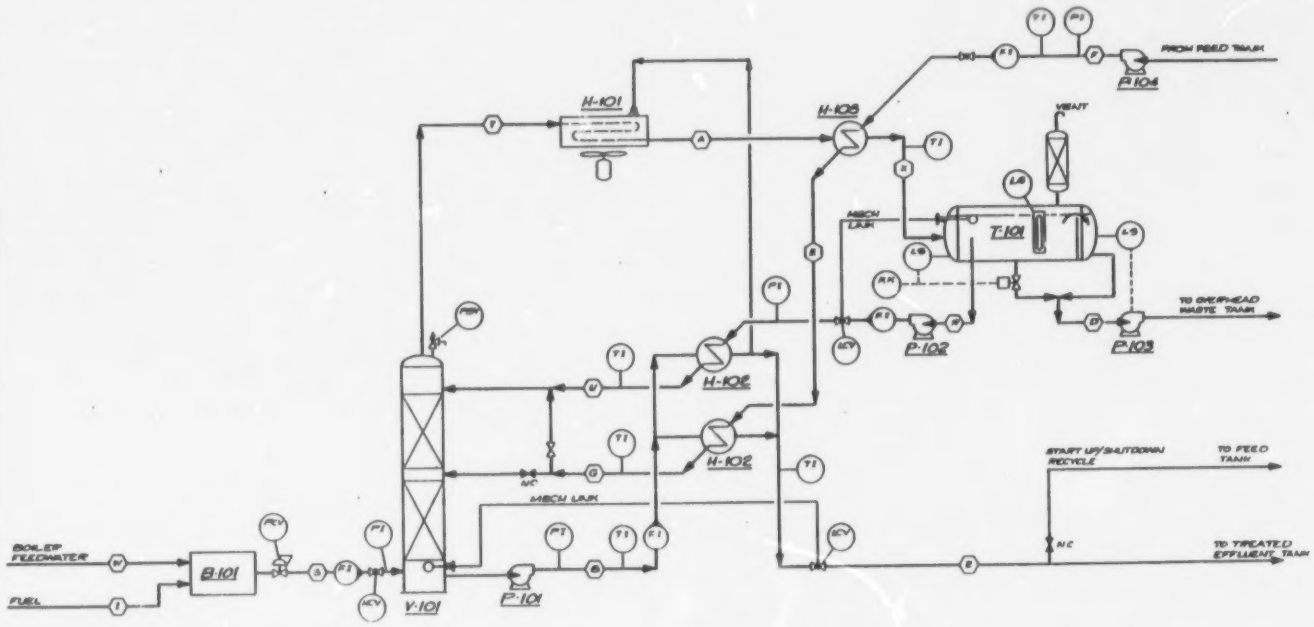
H-102
REFLUX/FEED PREHEATER
HEAT DUTY: 196 kW
HEAT TRANSFER AREA: 1.0 m²

P-102
REFLUX PUMP
FLOW: 8.9 L/min

T-101
OVERHEAD DECANTER
INLET FLOW: 6.8 L/min

P-103
OVERHEAD WASTE PUMP
FLOW: 0.8 L/min

P-104
FEED PUMP
FLOW: 20.8 L/min



STREAM NUMBER	STREAM NAME	MASS FLOW (kg/hour)	MOL. WT.	VOLUME FLOW (L/hour)	MASS ENTHALPY (kJ/hour)
0	STEAM (Typical)	4.7	18	316.1	28.5
1	FUEL	22.5	31	42.6	22.1
2	FUEL	22.5	31	28.2	48.7
3	FUEL	22.5	31	28.2	221.6
4	CONDENSED WATER	4.8	18	4.8	4.8
5	DEPLETED	5.7	18	5.7	5.7
6	DEPLETED	5.7	18	316.7	22.7
7	CONDENSED	4.3	18	324.4	18.4
8	CONDENSED CONDENSATE	4.3	18	316.4	4.3
9	CONDENSED	4.3	18	4.3	4.3
10	CONDENSED EFFLUENT	22.5	31	316.4	22.7
11	CONDENSED EFFLUENT	22.5	31	170.3	91.6
12	LIQUID FEEDSTOCK	0.7			
13	FUEL No. 2 Fuel Oil	0.6		1,000.0	

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DRN: I.R
CHK: GDG

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FOR APPROVAL
APPROVED FOR CONST. AT REV
APP. GDG
DATE 87.6.09

Chem Hill
Calgary Alberta
PROJECT NO. 7025190.A0

ENVIRONMENT CANADA

MOBILE STEAM STRIPPER
PROCESS FLOW DIAGRAM

DWG. NO. P-1
SCALE: NTS
SHEET ____
OF ____
REV. NO. 0

cooling medium. The ambient air temperature is assumed to be 15.6°C (60°F). In the event that the air temperature is higher, water will be sprayed on the condenser to lower the cooling temperature to the wet bulb temperature. For example, at a relative humidity of 20%, 50%, and 90%, the wet bulb temperatures for 25°C (77°F) dry bulb temperature are 12°C (53.6°F), 16°C (60.8°F), and 24°C (75.2°F) respectively. The corresponding values for 35°C (95°F) dry bulb temperature are 18°C (64.4°F), 26°C (78.8°F), and 33.5°C (92.3°F). Greater amounts of cooling are achieved with drier air.

In the event that the dew point is above 15.6°C (60°F), lower feed and steam flows would reduce the heat load on the condenser. Preliminary calculations show that at a dew point of 23.9°C (75°F), the feed would be reduced by 8% or the steam-to-feed ratio be reduced to 18% from the design 20%. At 32.2°C (90°F) dew point, the feed reduction required increases to 27% or the steam-to-feed ratio be reduced to 15%.

Total design heat duty of the air-cooler is 239 kW. For the subcooler, the heat duty is 38 kW which translates to a heat transfer requirement of 0.4 m^2 at design conditions.

The condensed and subcooled overhead stream enters the decanter where phase separation is allowed to take place. A residence time of 40 minutes is provided. The insoluble liquids will either float on top of or settle below the aqueous phase depending on their density and can be removed, while the aqueous phase is returned to the column as reflux The design reflux ratio is 12.6 (reflux/overhead waste) or 92.6%

of total overhead stream. A vent is provided on the decanter to vent uncondensible gases which would otherwise accumulate. The vent is open to atmosphere at about 6.10 m (20 ft) above ground. An activated carbon cartridge is also installed on the vent to remove trace organics when processing toxic pollutants such as styrene or acrylonitrile.

Both the reflux and the feed streams are preheated with treated effluent to 94.4°C (202°F). The heat duty of the reflux plate heat exchanger is approximately 33 kW and that of the feed 159 kW. Heat transfer area requirements are 1.6 m^2 and 7.9 m^2 respectively. The heat exchangers are mounted on the same frame and the relative areas can be adjusted mechanically if required. After heat exchange, the treated effluent will be cooled to 30.7°C (87.2°F). It is then pumped to storage for disposal and boiler feed supply.

The preheated reflux is introduced at the top of the column. While the feed normally enters the column with the reflux, provision is also made for it to be introduced 1.22 m (4 ft) of packing below the reflux. Such arrangement provides greater system flexibility than the preliminary design where the feed is combined with the overhead stream prior to entry to the decanter. The size of the decanter is significantly reduced and the turbulence and temperature rise resulting from mixing can be avoided. The current design, however, requires that the feed tank be provided with decanting capability.

Automatic controls are provided at critical areas where close control is required on a continuous basis. Liquid level at the base of the column will be automatically controlled since too high a level can cause flooding in the column and reduce separation efficiency, while too low a level can result in air-locking of the treated effluent pump, thereby impeding the operation of the whole system.

Liquid level in the decanter is another area requiring close control since a proper level must be maintained to prevent overhead contaminants from re-entering the system, and excessive aqueous phase from being discharged together with the overhead contaminants.

Manual control of the feed and steam flows and automatic dumping of separated hydrocarbons from the decanter are provided as are pressure and temperature gauges throughout the system. Boiler controls are included as part of the boiler package and are not shown.

4.4 FACILITIES DESCRIPTION

4.4.1 Modules

The equipment has been divided into four process modules to facilitate shipment and storage. The grouping of equipment has been designed to minimize field connections, minimize the extent of construction classified hazardous according to the electric code and to allow for flexibility to adapt to a variety of field layouts. Each module is fitted with lifting lugs, forklift slots, levelling jacks

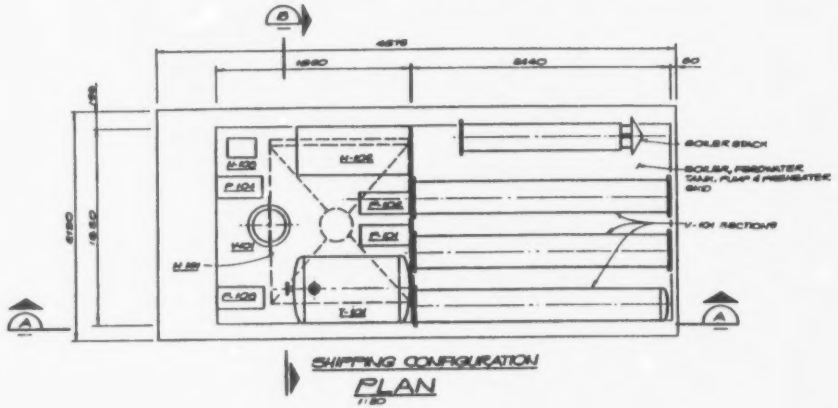
and lighting. The equipment is shown in both the shipping and erected configuration on Drawing No. M-1.

Boiler Module. The capacity of the boiler is rated at 30 HP (294 kW) and steam generation at saturation (100°C) is 7.84 kg/min i.e. 16% in excess of the steam requirement at 20% steam ratio with maximum design feed flowrate. The boiler is equipped with a fuel oil burner using No. 2 fuel oil. Fuel oil consumption at design condition is estimated to be 0.6 L/min. The fuel oil pump is built-in. Overall length of the boiler is 2.11 m (6' 11"), overall width 1.32 m (4' 4"), and overall height 1.52 m (5' 0").

For fire tube boilers, preheating the boiler feedwater is important to avoid thermal-shock. The water is heated with steam diverted from the boiler header to 82.2°C (180°F) or above in a 151 L (40 gal) feedwater tank. Oxygen is driven off at this stage as well. Storage capacity is estimated to be 25 minutes at design condition while the feedwater pump delivers 6.74 L/min of feedwater to the boiler for steam generation.

The boiler package is equipped with primary controls including low feedwater level shut-off and high-low burner firing. The boiler can be turned down to 25% of rated capacity. Overall dimensions are estimated at 2.44 m (length), 1.93 m (width), and 1.52 m (height). Total dry weight is estimated at 1070 kg.

The control panel for the overall process is located on this boiler module. The power supply for the



SHIPPING CONFIGURATION
PLAN
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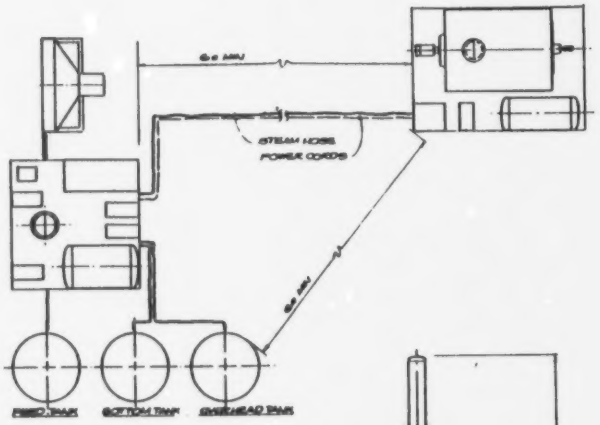

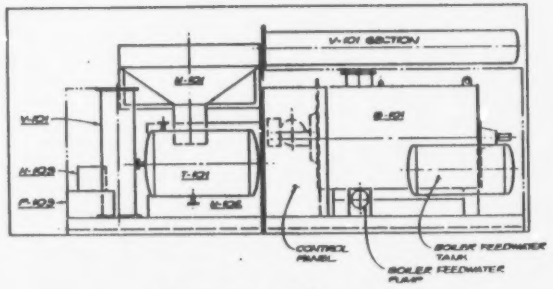

SECTION (A)
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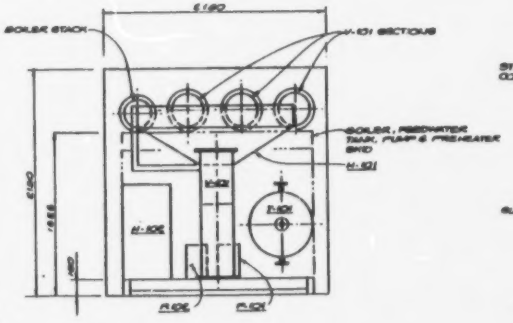

SECTION (B)
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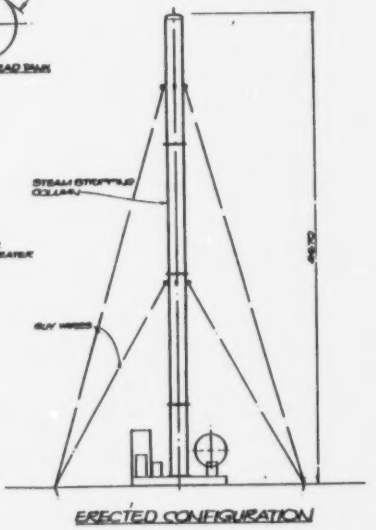

ERECTED CONFIGURATION

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CHK.	SDS

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CHAN HILL
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ENVIRONMENT CANADA

MOBILE STEAM STRIPPER
EQUIPMENT LAYOUT

DWG. NO. SS-1
SCALE
SHEET
OF
REV. NO. A

system will feed into the panel. All controls will be located in it and motors from other modules will be plugged in via flexible cables. This module will be electrically non-hazardous.

Process Module. This skid serves as the bottom support for the steam stripping column as well as a frame support for equipment including the decanter, reflux/feed preheater, overhead subcooler, feed pump, treated effluent pump, reflux pump and overhead waste pump. The bottom section of the column which is 1.22 m (4 ft) in length consisting of the gas inlet and liquid outlet is located in the centre of the skid. This arrangement is designed to minimize field connections. All electrical equipment on this system will be Class I, Division II.

Overhead Condenser. This is also known as a fin-fan air cooler which typically consists of a section of finned tubes, a steel supporting structure with plenum chambers and fin ring, axial-flow fan, drive assembly, and miscellaneous accessories such as louvres, fan guards, fencing and rail screens. The fins serve to extend the heat transfer area beyond the base area, thereby increasing the heat transfer coefficient. Aluminum is the most economical fin material for process streams up to 399°C (750°F). Electrical equipment on this module will be Class I, Division II.

Overall dimensions of the module are 1.32 m (width), 1.52 m (height), and 0.91 m (depth). Two rows of heat transfer tubes (25.4 mm O.D.) and a 1.5 kw fan are required. Overall weight is 450 kg.

Column Sections and Boiler Stack. This module consists of the remaining three column sections, and the boiler stack. The column sections are each 2.44 m (8 ft) in length and are fitted with packing, internals and associated piping including the overhead vapour line, reflux line, feed line and the decanter vent.

The boiler stack is 25 cm (9 3/4") in diameter and 1.52 m (5 ft) in length and includes a rain cap. These four pieces are secured to the top of the boiler schedule frame for shipping and removed for field assembly.

Accessories. In addition to the equipment identified on the process flow diagram, the following items will be required and have been included in the cost estimate.

Maintenance Equipment:

- extension ladder
- tool kit
- spare parts (gaskets, seals, etc.)
- interconnecting hoses and pipes

Safety Equipment:

- fire extinguishers
- first aid kit

4.4.2 Materials of Construction

Thin wall alloy construction is preferred to keep the weight down and to avoid solvent attack on

non-metals. Type 304 stainless steel is considered sufficient for the pilot unit except for the overhead system. Vapour exiting the column may contain hot chlorinated compounds that are very corrosive to stainless steel especially at lower pH. Hastelloy C-276 is resistant to chloride attack up to 10,000 mg/L at pH 4.5, whereas 300 series stainless can only tolerate chloride concentrations up to 80 mg/L at the same pH.

The overhead system also encounters the highest concentrations of volatile components in the process. Since wastes with various combinations, concentrations and types are to be treated, stainless steel may prove inadequate for this service.

Detailed evaluation of materials of construction is not included in this study. After preliminary assessment, it was decided that 904 stainless could be used for the overhead condenser, overhead subcooler and decanter. PTFE (teflon) can be used for the overhead waste pump. Detailed designs should include evaluation of materials such as titanium or Inconel Alloy 625. The relative costs (including fabrication) for 904 stainless, titanium, Alloy 625 and Hastelloy C-276 are estimated at 1.0, 1.4, 3.0, and 4.0 respectively. Piping materials can be selected from polypropylene, PVDF or stainless steel, depending on cost.

4.4.3 Logistics

To ease shipping and operation, the concept of skid-mounted, pre-assembled equipment modules was adopted. As stated in Section 4.4.1, four modules, namely, the

boiler module, process module, overhead condenser, column sections and boiler stack, are included.

Shipping by either box van with fork lift unloading or flatbed truck with crane unloading is feasible. The largest 5-ton box van commonly available for rental are 6.71 m (22') in length, 2.13 m (7') in width and 2.13 m (7') in height. The equipment has been arranged to fit within the most common door size, 2.13 m x 2.13 m and to fit within 4.88 m (16') overall length.

During shipping, the column sections and boiler stack would be secured and resting on the boiler module. The overall weight of the load is estimated at 4400 kg, which is within the legal limit for a 5-ton box van (7400 kg), but would be considered too heavy for a 1 ton box van (legal limit is 3860 kg).

The equipment layout, both for shipping and operation is presented in Drawing No. M-1.

Field set up time of the complete system is estimated to be about 16 hours with a 3-man crew assuming that ancillary equipment has been procured beforehand.

Field set up tasks would include:

- preparation of a level base, compacted gravel or other hard surface if not already available

- provision of electrical power either by temporary utility connection or portable generator

- provision of a portable fuel oil tank and fuel supply
- unloading and erecting the four equipment modules including interconnecting piping, hoses and power conductors
- provision and connection of feed tank and pump, waste hydrocarbon tank and treated effluent tank if required
- provision and connection of a boiler feedwater softening or demineralizing package

Since the boiler module is considered a source of ignition it should be located at least 6 m away from the remaining process equipment which is likely to contain hydrocarbons, to mitigate any fire hazards. Column and associated piping connections will be made from an extension ladder. Guy wires running from the top column section to anchors driven into the ground may be necessary to provide additional stability for the column.

4.5 TREATMENT CAPABILITY

4.5.1 Results From Computer Simulation

RCC's VACAD computer process program was used to calculate mass transfer efficiencies for 7 pollutants selected from the list of candidate compounds. The selection was made to reflect a range of physical properties. Design criteria were:

Column Diameter	305 mm
Packed Height	6.1 m
Feed Rate	2000 L/hr
Steam Rate	450 kg/hr max.

The results are presented in Table 4-2. Feed concentrations for all compounds except methanol (which has very high solubility in water) were assumed to be at half of their solubility limit at 25°C.

Compounds which do not dissolve readily in water were separated from the aqueous phase of the condensed overhead stream and subsequently removed while the aqueous phase was returned to the column. For situations where the contaminants are appreciably soluble in water, i.e. methanol and methyl ethyl ketone, the reflux stream was controlled.

The selected compounds; 1,1,1 trichloroethane, benzene, ethylene dichloride, methyl ethyl ketone, 2-methyl-1-butanol, methanol and pentachorophenol belong to the family class of alkyl halides, alphatic aromatic hydrocarbons, alkyl halides, ketones, alcohols, alcohols and phenols respectively. The results confirm literature published data and demonstrate the strippability of these compounds.

For methanol at a feed flow of 30.3 L/min with no reflux, overhead concentration of 20% can be achieved at a feed-bottoms concentration ratio of 143. For pentachlorophenol, the same separation can be attained at slightly lower feed rate. These two represent the least strippable compounds of the 7 simulated. 1,1,1 trichloroethane appears to be the

Table 4-2
PORTABLE COLUMN PERFORMANCE
ON SELECTED POLLUTANTS

Compound	Feed Flow (L/min)	Overhead (% of Feed)	Ratio (In/Out)	% Removal
1,1,1 Trichloroethane	26.5	20	11000	99.99
1,1,1 Trichloroethane	37.9	10	7300	99.99
1,1,1 Trichloroethane	121.1	1	1100	99.91
Benzene	26.5	20	10000	99.99
Benzene	37.9	10	6700	99.99
Benzene	121.1	1	1000	99.90
Ethylene Dichloride	26.5	20	11000	99.99
Ethylene Dichloride	37.9	10	6700	99.99
Ethylene Dichloride	121.1	~1	530	99.81
Methyl Ethyl Ketone	26.5	20	1100	99.91
Methyl Ethyl Ketone	37.9	10	476	99.79
Methyl Ethyl Ketone (Reflux = 90%, all cases)	121.1	1	20	95.0
2, Methyl, 1, Butanol	26.5	20	1000	99.90
2, Methyl, 1, Butanol	37.9	10	400	99.75
Methanol (Reflux = 0%)	30.3	20	143	99.3
Methanol (Reflux = 25%)	30.3	20	100	99.0
Methanol (Reflux = 50%)	30.3	20	63	98.4
Methanol (Reflux = 75%)	30.3	20	31	96.8
Pentachlorophenol	26.5	20	111	99.1
Pentachlorophenol	37.9	13	20	95.0

Notes:

1) All calculation based on 20 feet of packing
2) All compounds shown except methanol were assumed to have ½ their limiting solubility at 25°C as the feed concentration for these calculations.
3) The RATIO presented is the concentration in the feed divided by the concentration in the bottoms.
4) Reflux is based on % of overhead stream.

most strippable compound, followed closely by benzene and ethylene dichloride. Methyl ethyl ketone and 2-methyl-1-butanol are in the intermediate range with strippability better than that of methanol or pentachlorophenol.

Separation efficiency deteriorates with increasing feed flow as evidenced by the decreasing feed-bottoms concentration ratio. For example, with 500 mg/L incoming ethylene dichloride, the treated water would contain 0.045 mg/L of the contaminant at a feed flow of 26.5 L/min. With a 357% increase in flow, the concentration in the treated water increased to 0.94 mg/L, i.e. about a 20-fold increase.

In the case of methanol, deterioration of separation was observed with increasing reflux. This is because methanol is very soluble in water, increasing reflux essentially corresponds to a net increase in the feed flow.

Both ethylene dichloride and 1,1,1 trichloroethane belong to the alkyl halides family. Despite its higher molecular weight, 1,1,1 trichloroethane exhibits a higher vapour pressure and a lower boiling point than ethylene dichloride. Both are extremely strippable.

The aromatic hydrocarbons appear to be easily stripped. Benzene, toluene and ethyl benzene exhibit fairly high vapour pressure and Henry's Law constant, which contribute to their strippability. Styrene and isopropyl benzene display lower values. However, styrene's strippability remains high as evidenced by data reported in literature.

Significant removal of acetone, methyl ethyl ketone and methyl isobutyl ketone has been reported. Although both acetone and methyl ethyl ketone are appreciably soluble in water, they exhibit high volatilities and low boiling points. The strippability of methyl isobutyl ketone, on the other hand, is attributed to its relatively lower solubility in water and higher Henry's Law constant.

Despite its solubility in water, methanol and ethanol have been shown to have a good strippability. This can be attributed mainly to their low boiling points and high relative volatilities. 2-methyl-1-butanol appears to have better strippability than methanol. In contrast, ethylene glycol and propylene glycol are not strippable. Their relative volatility is low as evidenced by the high boiling points, and they also provide multiple sites for hydrogen bonding with the water molecules.

The simulated results have demonstrated the strippability of pentachlorophenol where conflicting results have been reported in literature. Implications are that relatively pure treated water can be attained at design feed flow for the compounds simulated. For easily stripped compounds such as trichloroethane, benzene and ethylene dichloride, a treated water concentration of $\frac{1}{10,000}$ that of the feed concentration can be achieved. Other less strippable components such as methanol and phenols may have difficulty achieving such high treated water purity.

4.5.2 Off-Normal Condition

Maximum feed concentration, for design purposes, has been taken to be the solubility limit of the compound under consideration. Wastewaters with concentration of compounds exceeding their solubility limits will have the excess decanted from the feed tank.

4.5.3 Effect of Column Height

Mathematical simulation of mass transfer in packed columns makes use of the concept of transfer units. The number of transfer units depends on the inlet and outlet concentrations of both streams and on the vapour liquid equilibrium data. The height of a transfer unit depends on the physical characteristics of the system including flows, viscosity, diffusivity, etc. For a system in which only the height of packing varies, the height of a transfer unit will remain the same and the number of transfer units will vary proportionately. In dilute systems such as being considered here, the number of transfer units is nearly proportional to the natural log of the ratio of inlet to outlet concentrations in the liquid phase. The effect of reducing the packing height to 3.05 m (10') will reduce the logarithm of the ratio of inlet to outlet concentrations by a factor of two.

The effect of reducing packing height to 3.05 m on the removal ratio for several of the compounds is listed in Table 4-3.

Table 4-3
COLUMN PERFORMANCE WITH 3.05 m PACKING

Compound	Feed Flow L/Min	Overhead (% of Feed)	Ratio (In/Out)	% Removal
Pentachlorophenol	26.5	20	10.5	90.50
Ethylene Dichloride	37.9	10	81.8	98.78
Benzene	37.9	10	81.8	98.78

For compounds with a high relative volatility the effect on percent removal is low, however, it must be noted that for equal feed concentrations the effluent concentration from the shorter column would be 50 to 100 times higher. Performance on compounds with a low relative volatility is much noticably poorer, with percent removal dropping by several points.

4.5.4 Computer Model

This system will be required to respond to a wide and somewhat unpredictable range of types and concentrations of pollutants. Each set of conditions will require a different set of process parameters for optimum operation. Field optimization would be a time consuming task without substantial home office support.

It is recommended that a computer model be developed specific to the system to assist in determining the optimum feed rate, steam rate, reflux rate etc. This is not included in the capital cost estimate.

4.6 OPERATOR QUALIFICATIONS

Operation of the specified boiler does not require special qualifications in Ontario, Alberta or Saskatchewan. Other provinces were not surveyed, but are assumed similar.

4.7 UTILITY REQUIREMENTS

The following utilities are required at the rates and conditions noted to support the steam stripper system.

Fuel: No. 2 fuel oil, 860 litres per day. Portable tank and regular deliveries required.

Electric Power: 220/208 V/60 Hz/single phase, 5 kw, 90% power factor. (Heat tracing loads not included).

Boiler Feewater: 6.7 L/min fresh or treated water from the stripper softened to < 1 mg/L total hardness.

Chapter 5
COST ESTIMATES

5.1 CAPITAL COST ESTIMATE

A capital cost estimate was prepared for the facilities indicated on the process flow schematic. This includes all equipment, assembly labour and materials for skid mounting/pre-assembly of the modules, piping and valves, instrumentation, electrical and control panel, and accessories. Estimates for construction overhead and profit, and engineering are also included.

Items required for a complete system but not included in the cost estimate are boiler feedwater treatment system, fuel oil tank, overhead waste tank, and treated effluent tank. Owner's costs for project management and control are not included.

The capital costs were developed in three parts; equipment costs, assembly material and labour costs, and indirect costs. The equipment costs cover costs of individual items and are based on vendor budget-pricing information or in-house historical data. The pricing basis is second quarter 1987, F.O.B. Calgary with duty, taxes and freight included, where applicable. This facility is assumed to be exempt from Federal Sales Tax.

The assembly material costs include piping, valves, instrumentation, electrical and materials required for skid mounting of various modules. The materials for the latter include items such as structural steel, brackets, paint, and other bulk materials.

The assembly labour cost applies to the activities associated with assembling the various modules. These include:

- steelwork - supports, structural members
- equipment setting
- piping
- instrumentation
- electrical
- insulation
- painting

The components of the costs were developed by estimating the manpower requirements for each element of the activities involved by category of personnel required (welders, fitters, labourers, etc.).

The indirect costs are comprised of two components and were estimated as follows:

Construction Overhead and Profit (100% of direct labour)

- Procurement
- Purchase
- Expedite
- Inspect
- Project Management

Engineering (estimated at $30,000)

- Detailed design drawings
- Detailed equipment specifications
- Engineering services during construction

Table 5-1 presents both the equipment list and the estimated capital cost for the pilot unit.

5.2 OPERATING COST ESTIMATE

The operating cost is presented in Table 5-2 and can be divided into four categories:

- Transportation
- Set-up
- Dismantle
- Operation

The first three are incurred for each occurrence or operating site. The fourth is incurred per operating day.

Transportation. The cost components include truck rental, fuel, and labour. Using the following basis:

i) 500 km one way (per day)
ii) fuel consumption = 20 L/100 km
iii) labour = 8 hr/day

The transportation cost each day amounts to $400.

Set-Up. A fork lift and a boom truck are required to unload equipment from the box van and for set-up. On the basis of 8-hr rental and 16 hours of set-up time (2-man crew plus 8-hour availability of boom truck operator), the estimated cost per set-up is $1,500.

Dismantle. Essentially the same cost components (type and magnitude) for set-up are required for dismantling and loading. The cost is estimated at $1,500.

TABLE 5 - 1
ENVIRONMENT CANADA
EQUIPMENT LIST

EQUIPMENT NUMBER	EQUIPMENT NAME	DESIGN BASIS	DESIGN DETAILS	REMARKS	EQUIPMENT COST	COMMENTS
(1) EQUIPMENT COST						
B-101	BOILER	HP = 30 Capacity= 453 kg/h steam Fuel Oil Consumption = 0.6 L/min	Length (mm) : 2108 Width (mm) : 1295 Height (mm) : 1524	Stack Dimensions: Diameter: 248 mm Length: 1524 mm	$16,000	Add $2,500 to weatherproof
H-101	OVERHEAD CONDENSER	Heat Duty = 239 kw Air Cooler Inlet Ambient Air = 60 F	Width (mm) = 1321 Height (mm) = 1524 Depth (mm) = 914	904 Stainless Tube 25.4 mm (O.D.) Tube 914 mm Dia. fan	$13,000	
H-102	REFLUX/ FEED PREHEATER	Heat Duty = 192 kw Heat Transfer Area = 10 m2 Plate heat Exchanger	Length (mm) = 853.4 Width (mm) = 407.0 Height (mm) = 1012 50 plates	Model A-10B Frame: Carbon Steel Nozzle: S.S. Plate: S.S. Gasket: Viton Connection: S.S.	$6,500	
H-103	OVERHEAD SUBCOOLER	Heat Duty = 38 kw Heat Transfer Area = 0.4 m2 Plate heat Exchanger	Length (mm) = 260 Width (mm) = 100 Height (mm) = 480 18 plates	Model P-01 Frame: Carbon Steel Nozzle: Hastelloy lined C.S. (904 SS not standard) Plate: Hastelloy C-276 Gasket: Viton Connection: S.S.	$4,000	
P-101	TREATED EFFLUENT PUMP	1 x 100% unit Flow: 39.5 L/min Head: 120 kPa	Horizontal, End Suction S.S. Wet Area 1800 rpm		$1,000	
P-102	REFLUX PUMP	1 x 100% unit Flow: 5.9 L/min Head: 200 kPa	Gear Pump S.S. Wet Area 1000 rpm		$800	
P-103	OVERHEAD WASTE PUMP	1 x 100% unit Flow: 0.5 L/min Head: 50 kPa	Gear Pump PTFE Wet Area 200 rpm		$1,100	
P-104	FEED PUMP	1 x 100% unit Flow: 33.3 L/min Head: 200 kPa	Horizontal, End Suction S.S. Wet Area 1800 rpm		$1,000	

TABLE 5 - 1
ENVIRONMENT CANADA
EQUIPMENT LIST

EQUIPMENT NUMBER	EQUIPMENT NAME	DESIGN BASIS	DESIGN DETAILS	REMARKS	EQUIPMENT COST	COMMENTS
T-101	OVERHEAD DECANTER	Inlet Flow: 6.3 L/min	Material : 904 stainless Length (mm) : 914 (T/T) Diameter (mm) : 610		$4,500	
V-101	STEAM STRIPPING COLUMN	Steam/Feed ratio = 20% (w/w) Feed = 33.3 L/min Material: SS904 Insulated 3 sections each of 2438 mm length	Diameter (mm) = 305 Overall Height (mm) = 8382 Packing Height (mm) = 6090 Packing: 25.4 mm Pall Ring		$22,000	
E-101	BOILER FEEDWATER SYSTEM	Feedwater Tank : 151 L Feedwater Pump Steam Preheater	Length (mm) : 1219 Width (mm) : 610 Height (mm) : 1219		$3,200	
					$73,100	

(II) ASSEMBLY COST

Include assembly material and labour costs.
Material costs include piping, valves, instrumentation, electricals and materials for skid mounting of of various modules (structural steel, brackets, paint and other bulk materials).

BOILER MODULE (With Control Panel)		$10,400
PROCESS MODULE		$20,400
COLUMN ATTACHMENTS		$6,100
OTHERS		$4,000
	Direct Labour ($10,000) and Materials ($30,900) =	$40,900

(III) INDIRECTS

CONSTRUCTION OVERHEAD & PROFIT (100% of direct labour)	$10,000
ENGINEERING	$30,000
TOTAL	$154,000

TABLE 5 - 1
ENVIRONMENT CANADA
EQUIPMENT LIST

EQUIPMENT NUMBER	EQUIPMENT NAME	DESIGN BASIS	DESIGN DETAILS	REMARKS	EQUIPMENT COST	COMMENTS

NOT INCLUDED:

BOILER FEEDWATER TREATMENT SYSTEM

FUEL OIL TANK

OVERHEAD WASTE TANK

TREATED EFFLUENT TANK

OWNER'S COSTS

Table 5-2
ENVIRONMENT CANADA
OPERATING COST

Category	Component	Unit	Unit Cost	Usage In Units	Total Cost
Transportation	Box Van Rental (5-Ton)	day	$65.00	1	$ 65
(Basis: 500 km one way	Distance travelled	km	0.25	500	125
	Fuel for vehicle (diesel)	L	0.39	100	39
	Staff[1] (driver)	hr	22.50	8	180
					$ 400
Set-Up	Fork Lift Rental	hr	40	8	320
	Boom Truck	hr	50	8	400
	Rental (includes operator)	km	1.20	50	60
	Staff[1]	hr	22.50	32	720
					$1,500
Dismantle	Fork Lift Rental	hr	40	8	320
	Boom Truck	hr	50	8	400
	Rental (includes operator)	km	1.20	50	60
	Staff[1]	hr	22.50	32	720
					$1,500
Operation (Basis: one day)	Staff[1]	hr	22.50	24	540
	Utilities[2] (electric energy)	kw-hr	0.05	120	6
	Fuel (No. 2 Fuel Oil)[4]	L	0.25	864	220
	Maintenance[3]	day	80	1	80
					$850

Notes:
1 Base salary plus 30% salary burden
2 Composite demand and electric charge
3 Assume to be 10% of total capital cost per annum, 200 operating days per year
4 Bulk sale

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Operation. One operator's around-the-clock attention is considered sufficient for the operation of the design facilities. Other cost components include electric energy and maintenance. Estimated costs per operating day are:

Labour	24 hr x $ 22.50/hr	$	540
Electric Power	120 kw hr x $ .08/kw hr	$	10
Fuel	864 L/day x $ .25/L	$	220
Maintenance	10% of capital cost over 200 operating days	$	80
	TOTAL	$	850

This cost does not include rental or demurrage of ancillary equipment. Operating labour is equivalent to one person 24 hr/day. It would be best to have another person in the area for safety reasons, but a second person is not required for direct operating tasks.

5.3 Cost Variation With Size

Both the capital and the operating cost components are not very sensitive to size, i.e. minimal cost savings can be realized with a smaller design flow. This can be attributed to the phenomenon that most capital cost components in the size range being considered either:

i) remain relatively unchanged in cost despite changes in physical size e.g. piping and valves, boiler, column, assembly materials

ii) remain relatively unchanged in physical dimensions despite changes in design flow e.g. pumps or

iii) remain unchanged in both cost and physical dimensions despite changes in design flow e.g. instrumentation, electrical panel, accessories and assembly labour which are considered fixed cost components

For example, boilers with 30 HP and 40 HP capacity differ by less than 5% in cost. With a reduced design flow, a smaller column diameter may be warranted but the column height remains the same in order to provide the same mass transfer efficiency. While the reduction in diameter may reduce the material costs, fabrication cost may be increased due to the very small scale. In addition, as the column becomes more slender, additional external support will be required.

Minor cost savings may be realized with a smaller overhead subcooler or reflux/feed preheater. Since the overhead condenser and decanter are to be custom-built with exotic material, reduction in cost, if any, will be minimal.

Overall, we would not expect an exponent greater than 0.2 in the equation

$$\left[\frac{\text{Cost 1}}{\text{Cost 2}}\right] = \left[\frac{\text{Capacity 1}}{\text{Capacity 2}}\right]^{\text{exponent}}$$

Operating cost components include predominantly fixed cost components, primarily operating labour. A

marginal reduction in transportation cost could be realized if the physical size and the weight of the load could be reduced to such an extent that a 1-ton instead of a 5-ton box van can be used. This is not likely to be achieved given the insensitivity of the equipment size to flow as discussed above.

5.4 ACCURACY OF THE ESTIMATES

The cost estimates were prepared for the purpose of preliminary process evaluation. They are based on equipment takeoffs from process flowsheets and as a result, are preliminary in nature. The final costs of the project will depend on actual labour and material costs, competitive market conditions, final project scope and location, implementation schedule, and other variable factors.

Cost estimates prepared from the level of detail provided herein are normally considered to have an accuracy of +30%/-15%.

Chapter 6
CONCLUSIONS

As a result of the preliminary design development and mass transfer calculations done during this study, a number of conclusions can be drawn.

1. Removal of a large number of volatile organic compounds from water to very low levels is possible using steam stripping.

2. It is possible to design a steam stripping system with 2000 L/hr capacity that can be knocked down for shipment in a commercial rental truck and be set up in less than 24 hours using readily available equipment.

3. The estimated capital cost of such a steam stripping system is $154,000, +30/-15%.

4. The operating cost of the system is estimated at $ 850/day plus transport.

5. Within the range of 400 - 2000 L/hr of feed, the cost of the system varies only slightly.

6. Reducing the height of the column from 6.1 to 3.05 metres of packing has a relatively small influence on percent removal, however since the effluent concentration is low, a small change in percent removal can affect the effluent concentration by one or two orders of magnitude.

7. Given that there is a need for removal of volatile organics from water at various sites on a short term basis and that the cost is acceptable, it is concluded that a mobile steam stripper is a feasible method of dealing with such situations.

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